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(12) **United States Patent**
Goldstein et al.

(10) **Patent No.:** **US 8,248,457 B2**
(45) **Date of Patent:** **Aug. 21, 2012**

- (54) **OPTICAL DEVICE**
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- (73) Assignee: **Visionsense, Ltd.**, Petah Tikva (IL)
- (*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 824 days.

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(21) Appl. No.: **09/785,791**

(22) Filed: **Feb. 16, 2001**

(65) **Prior Publication Data**
US 2001/0033326 A1 Oct. 25, 2001

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/257,850, filed on Feb. 25, 1999, now Pat. No. 6,396,873, and a continuation-in-part of application No. 09/699,624, filed on Oct. 30, 2000, now Pat. No. 7,154,527.

(51) **Int. Cl.**
H04N 13/00 (2006.01)

(52) **U.S. Cl.** **348/42**; 348/49; 348/57; 348/46; 348/51; 348/43; 348/44; 348/59; 348/45; 348/54; 600/166; 600/109; 250/201.8

(58) **Field of Classification Search** 348/42, 348/49, 57, 46, 51, 43-44, 59, 45, 54, 70, 348/208, 65-66, 61, 69; 600/111, 166, 109; 250/201.7, 201.8; 359/824, 813, 826, 823; 356/4.04; 396/113

See application file for complete search history.

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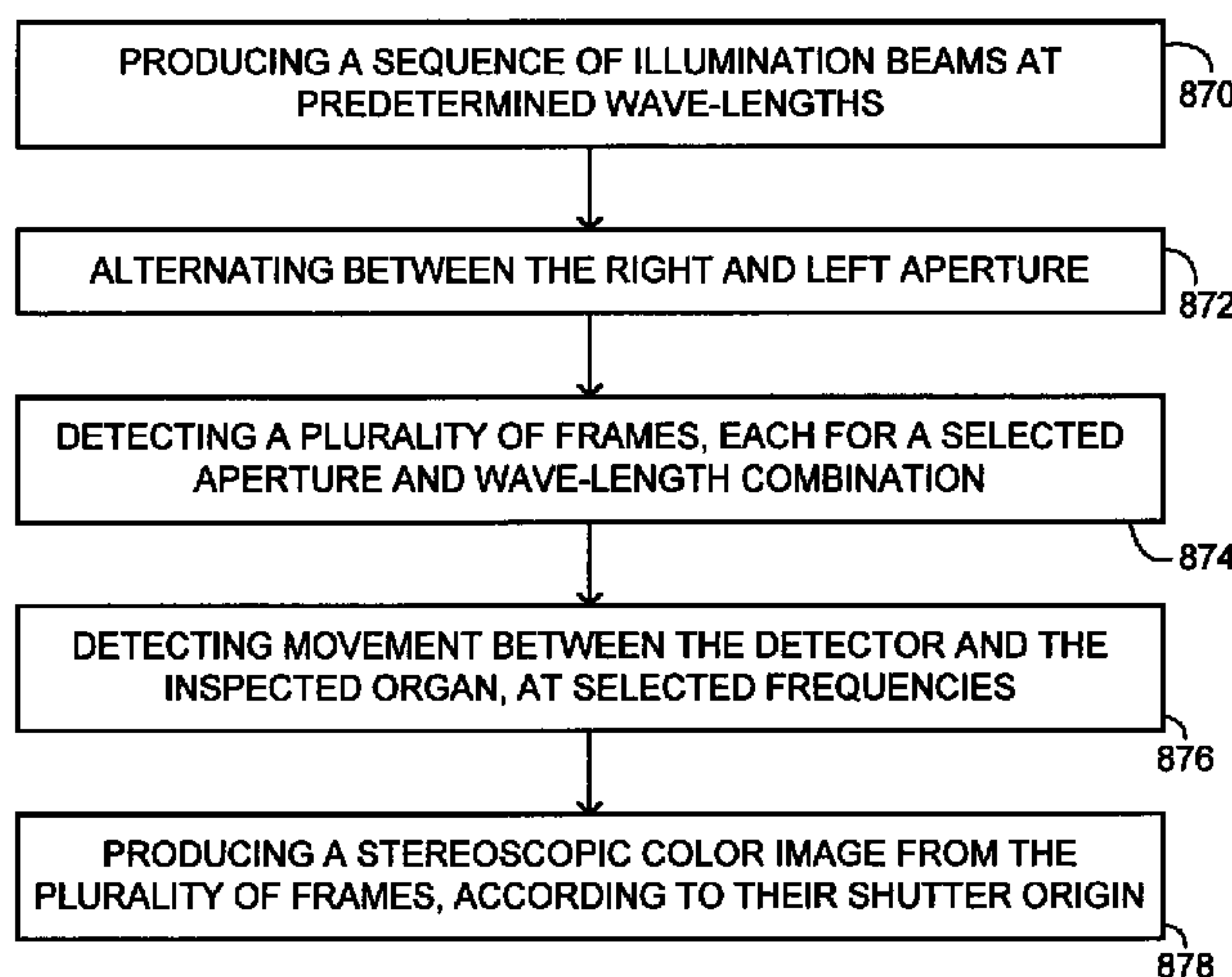
Primary Examiner — Shawn An

(74) *Attorney, Agent, or Firm* — Merchant & Gould P.C.

(57) **ABSTRACT**

A stereoscopic device including a sensor assembly for detecting a sequence of stereoscopic images of an object, a movement detector for detecting the movements of the sensor assembly relative to the object, and a processing unit connected to the sensor assembly and to the movement detector, wherein the processing unit selects portions of the stereoscopic images, according to a signal received from the movement detector, thereby producing a visually stable sequence of display images.

34 Claims, 26 Drawing Sheets



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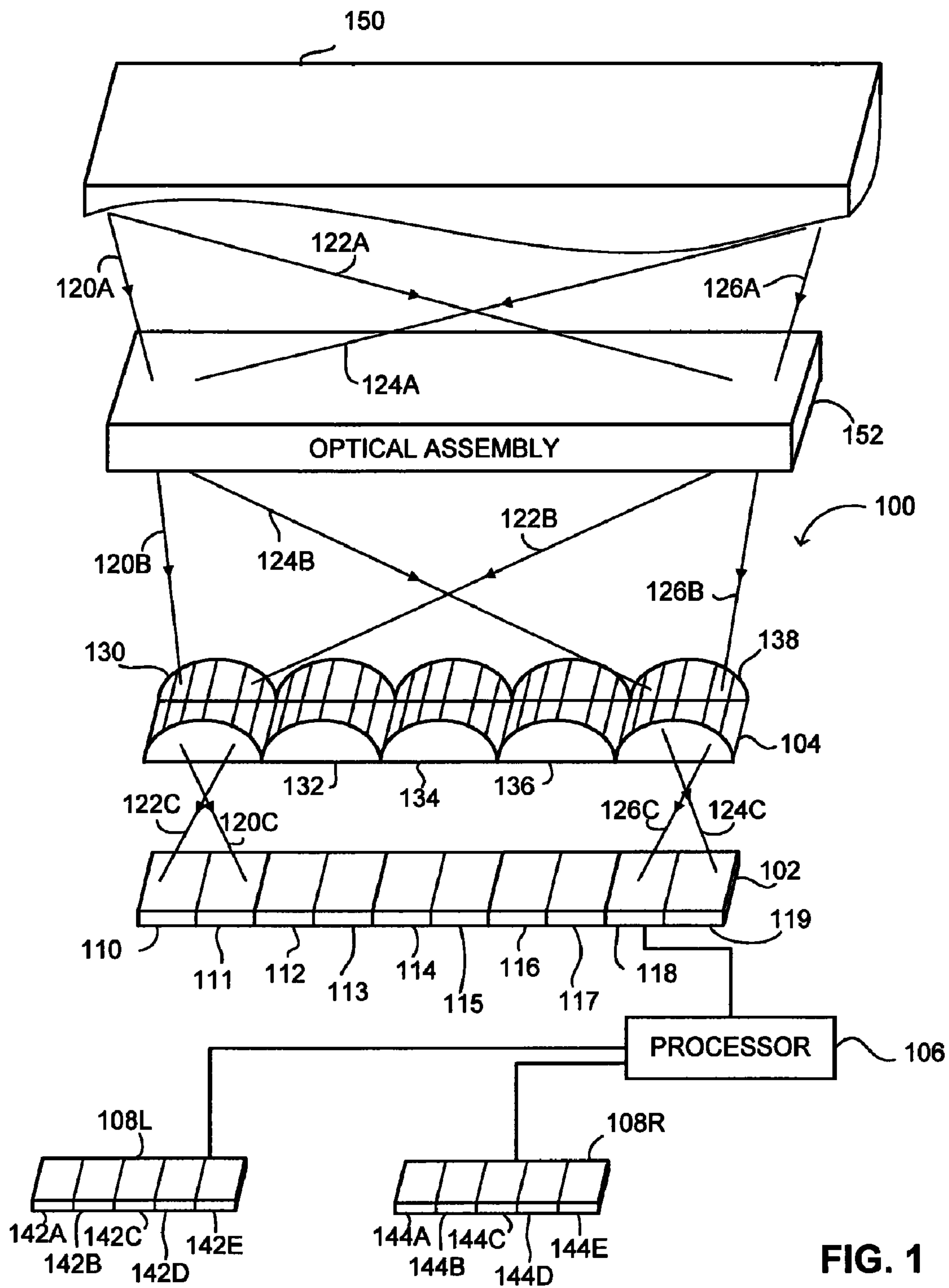


FIG. 1

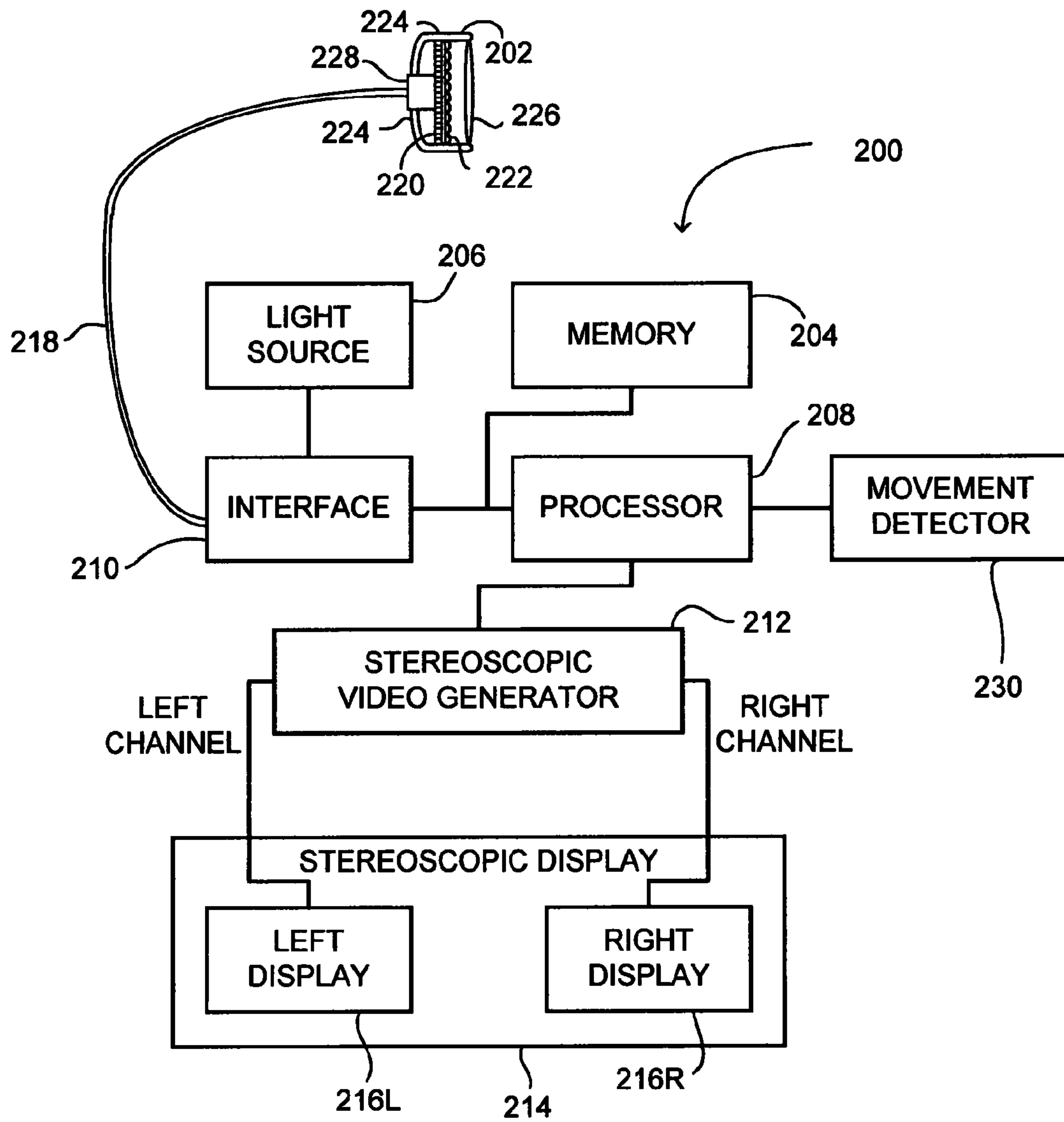


FIG. 2

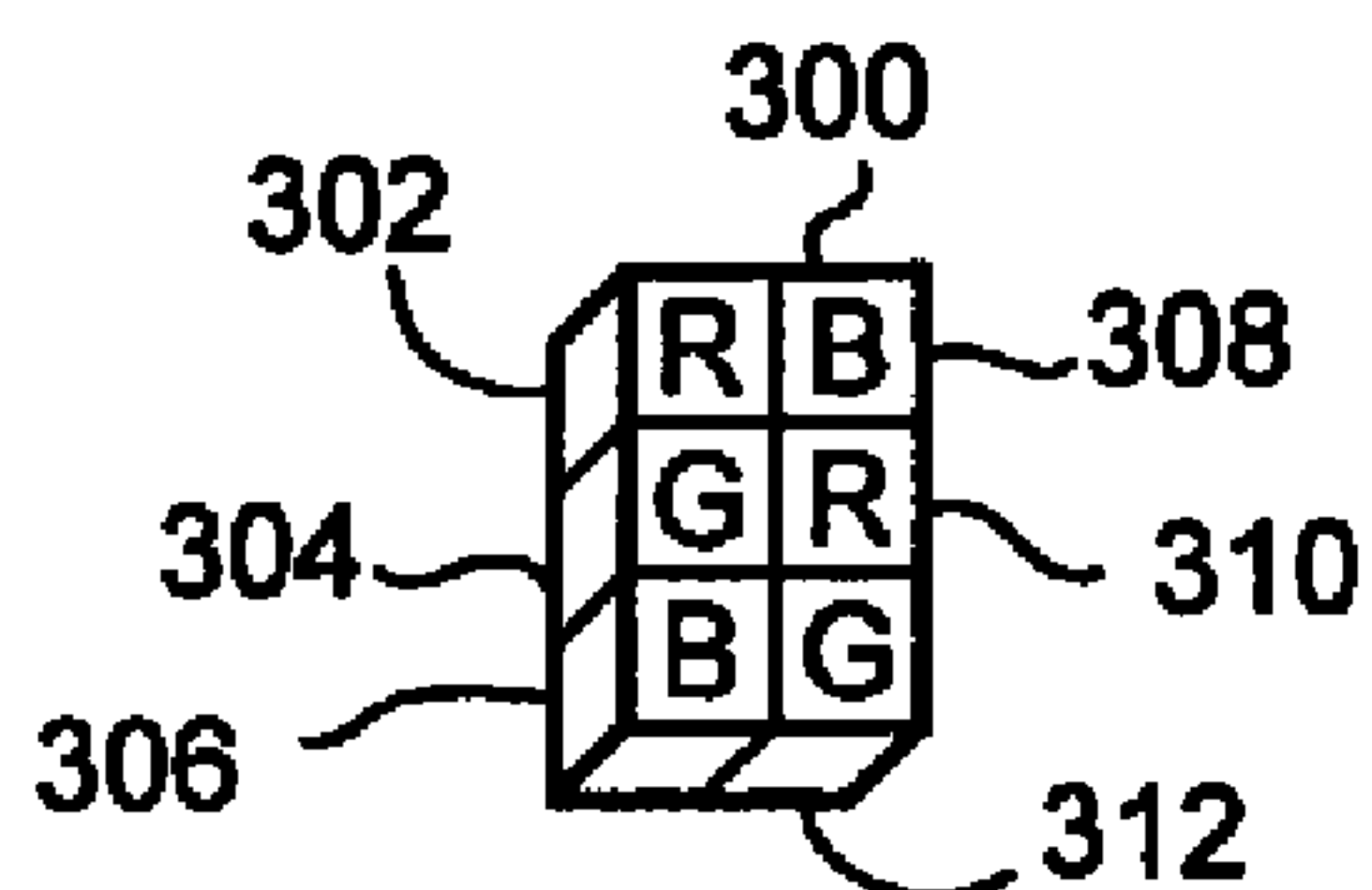


FIG. 3A

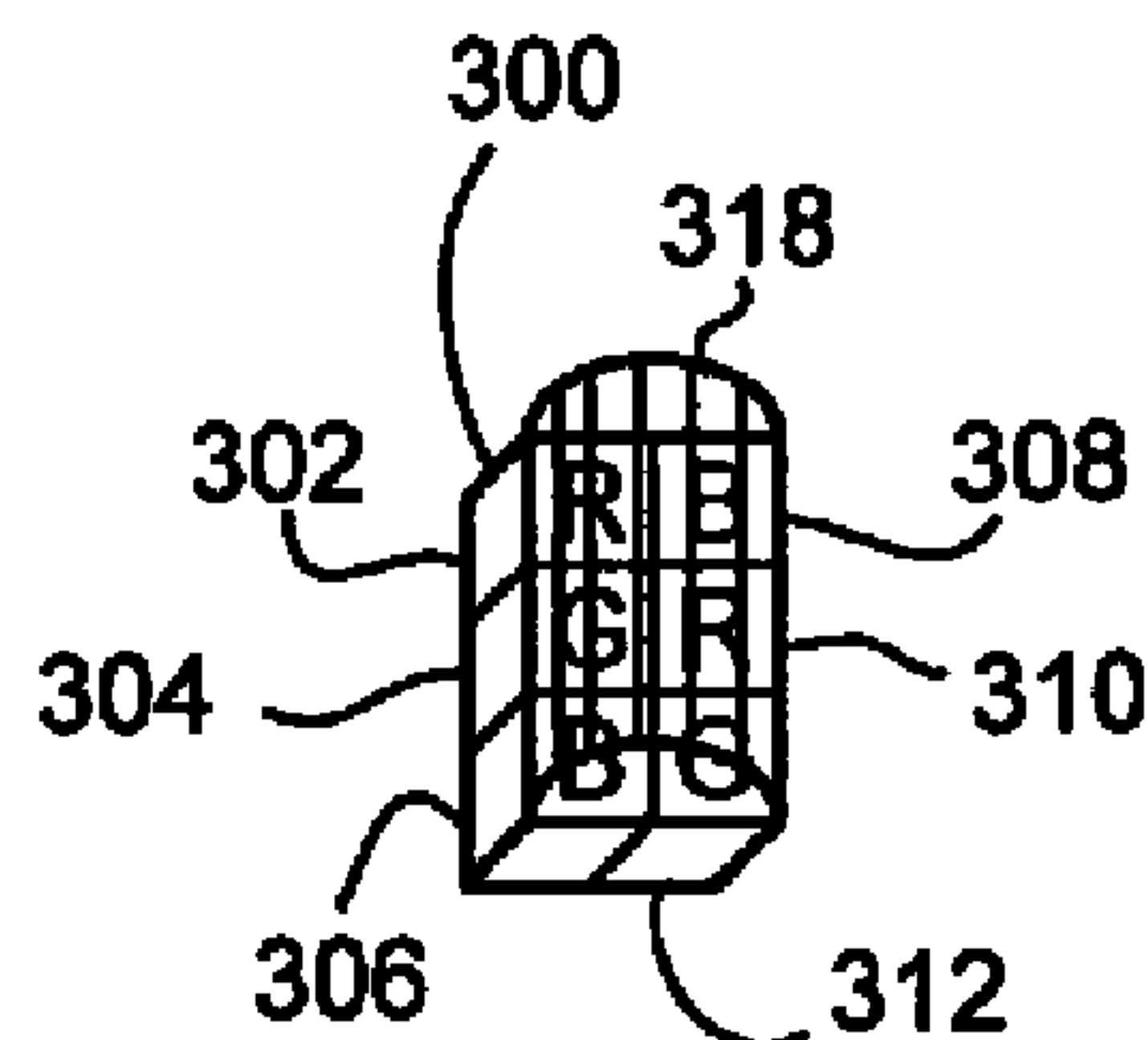


FIG. 3B

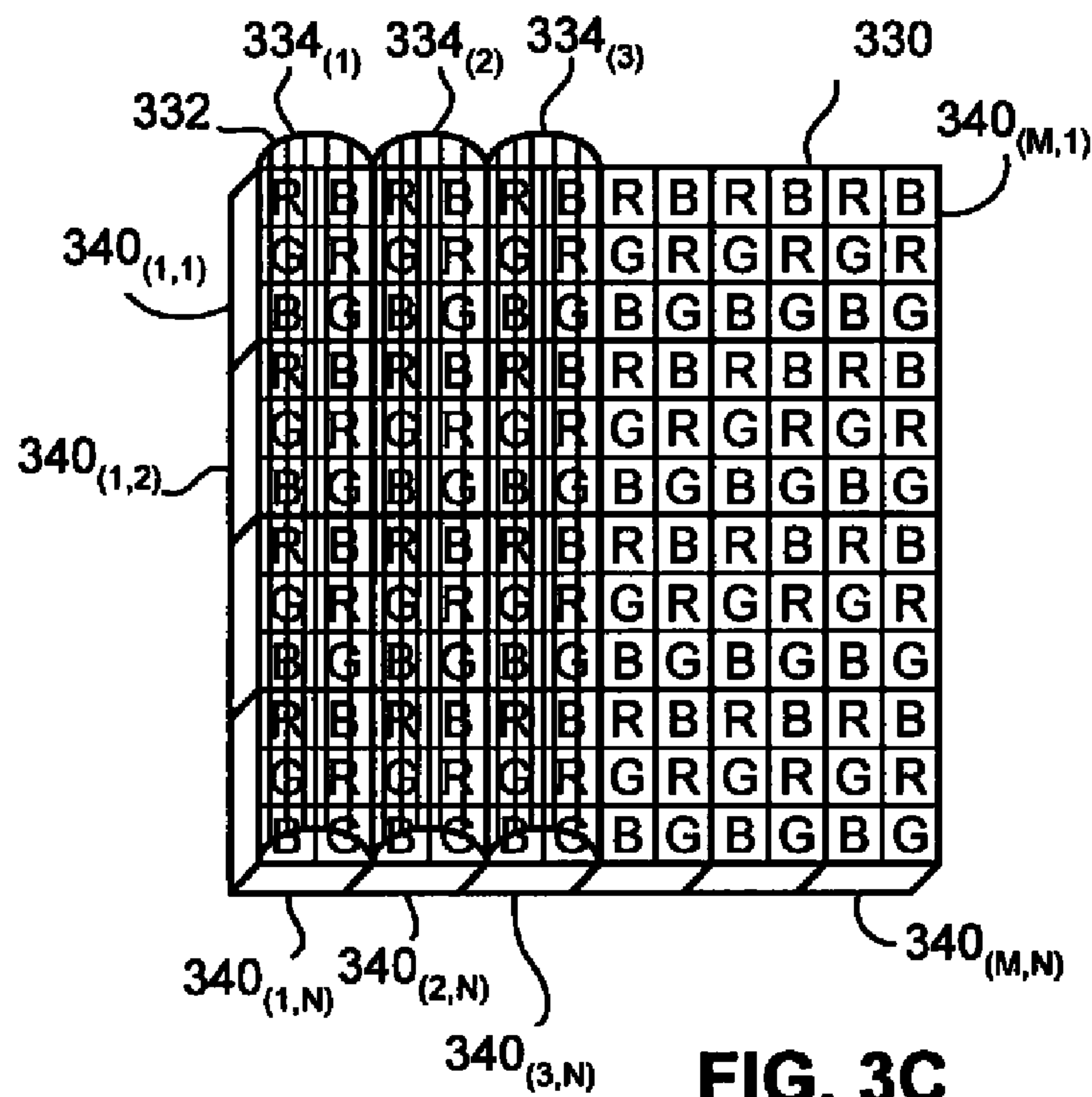


FIG. 3C

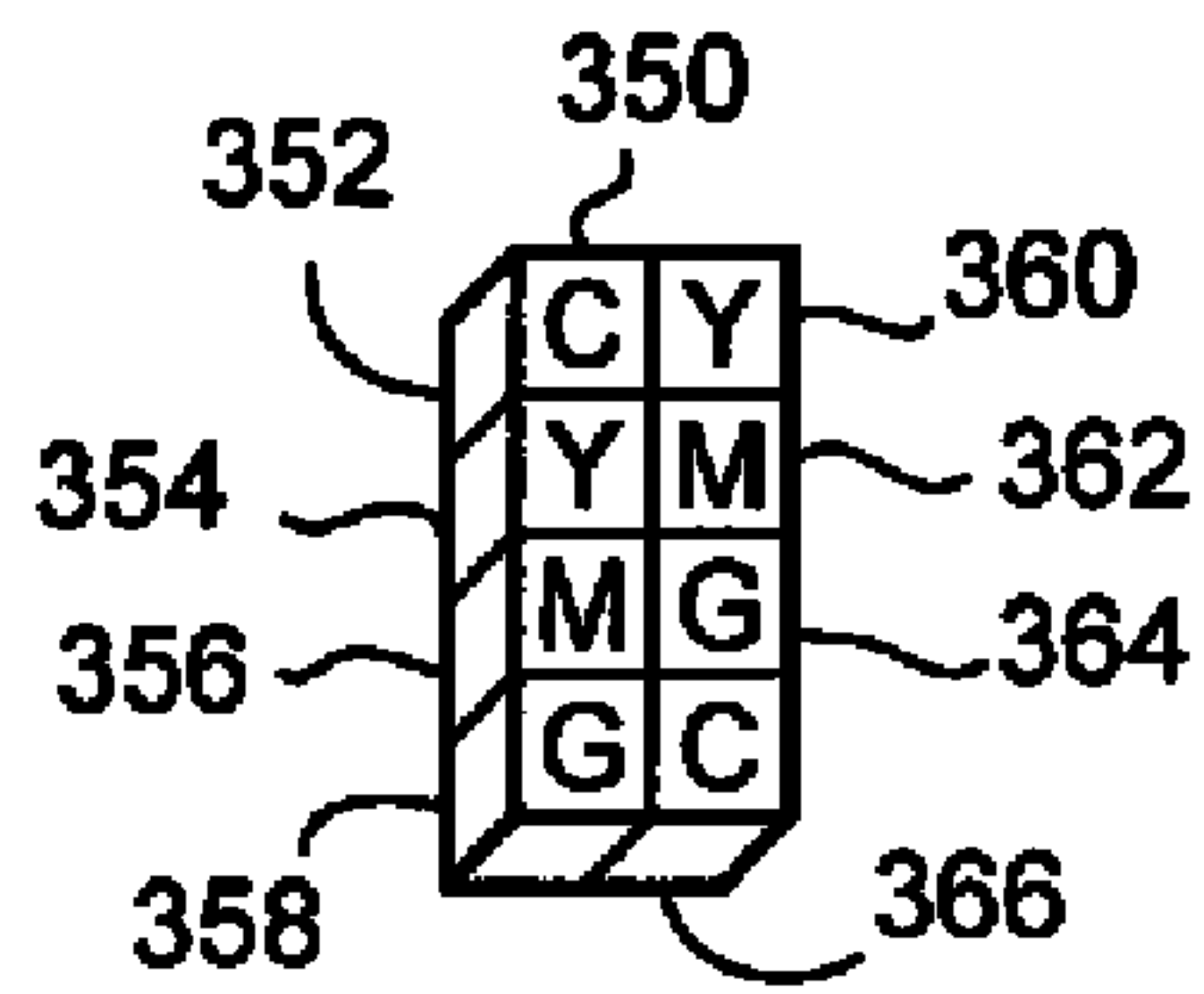


FIG. 4

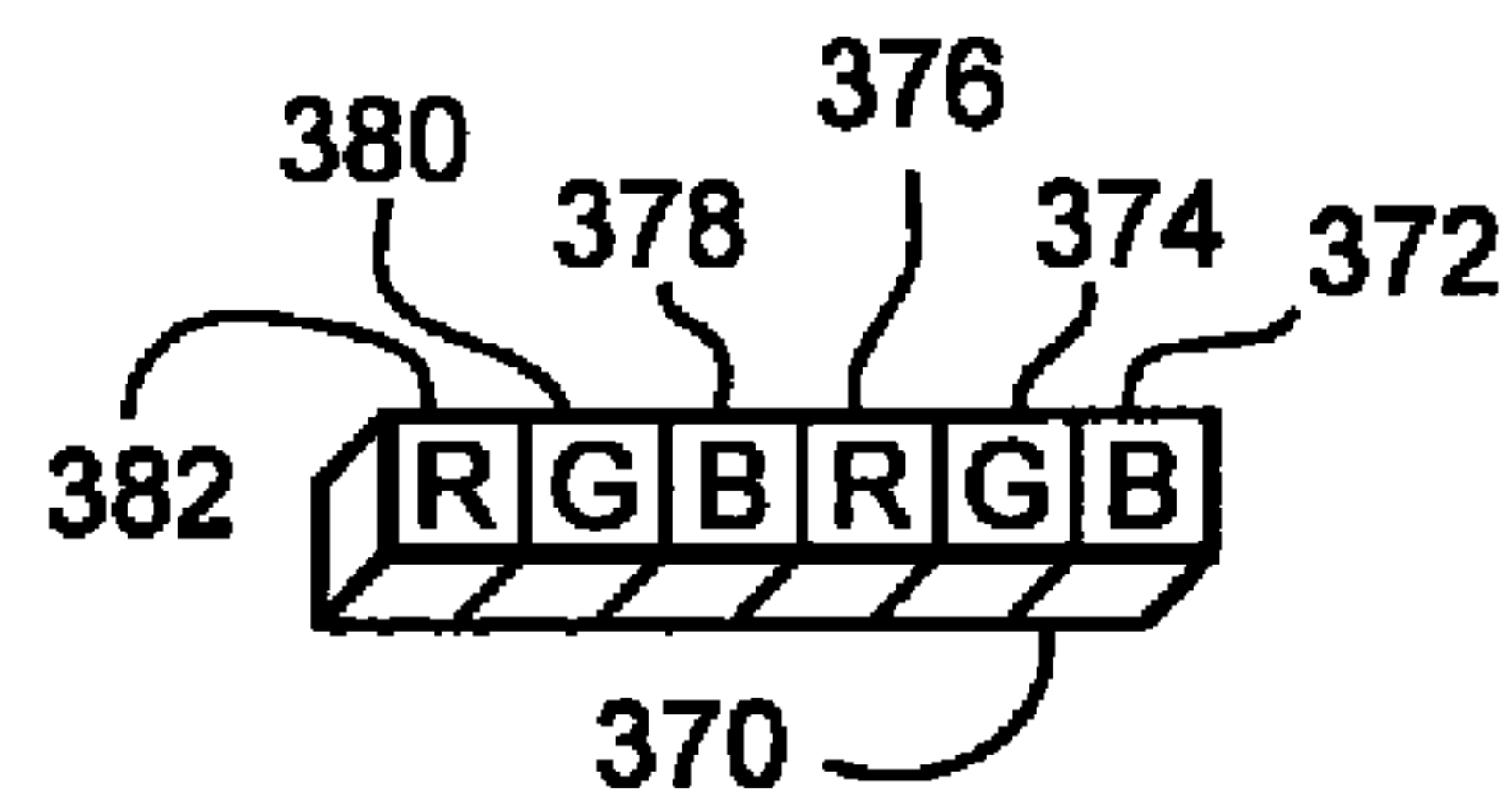


FIG. 5A

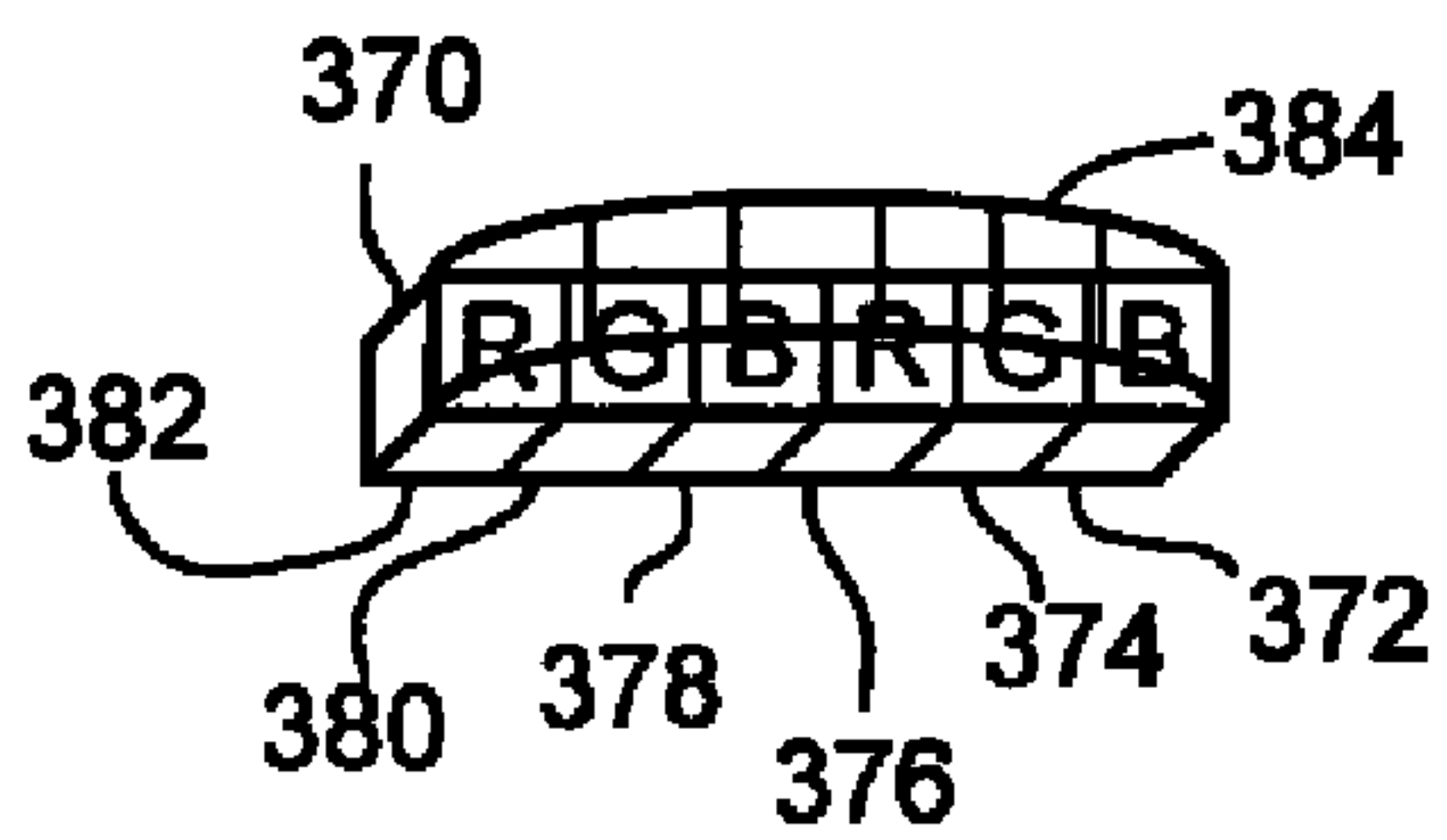


FIG. 5B

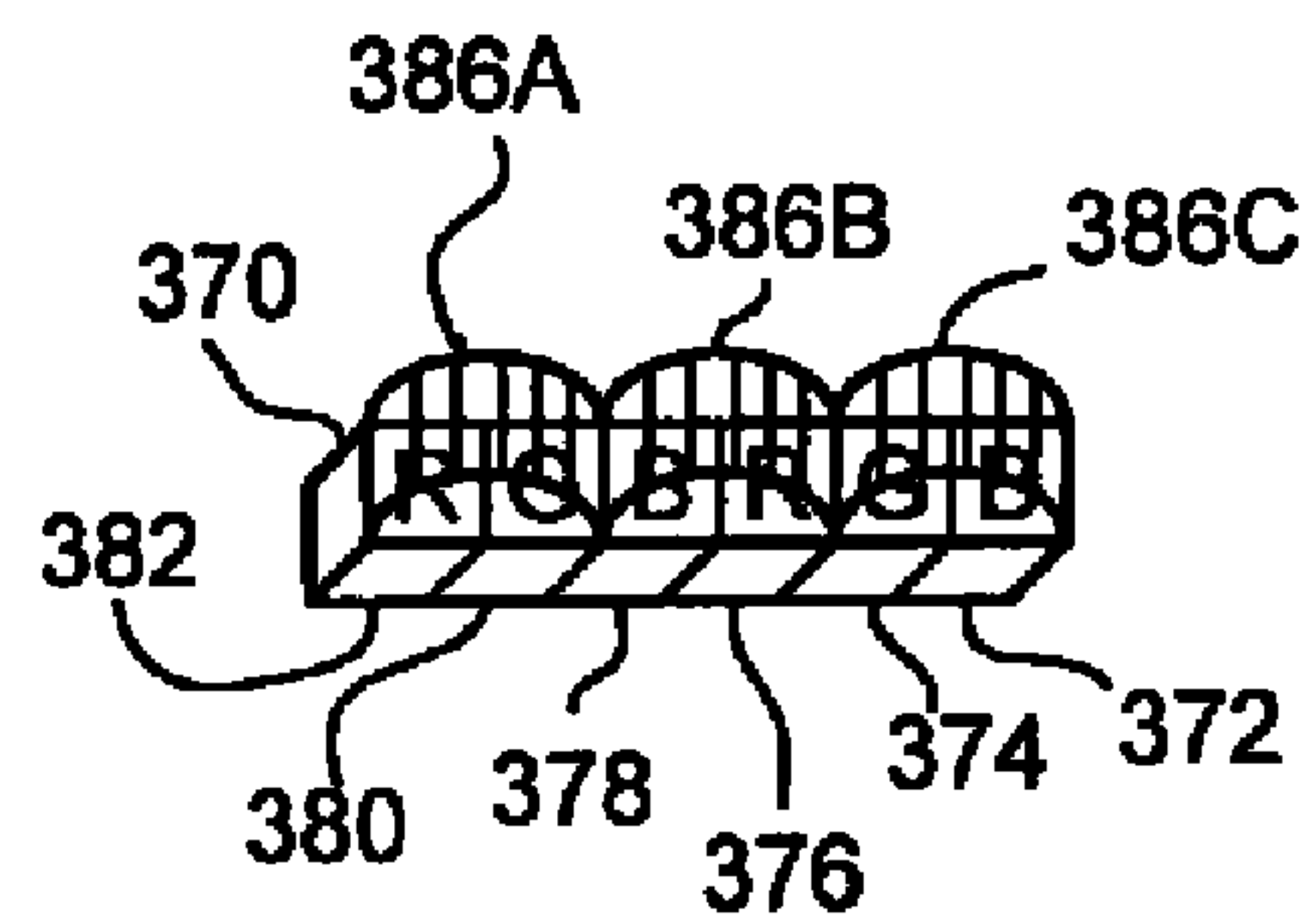


FIG. 5C

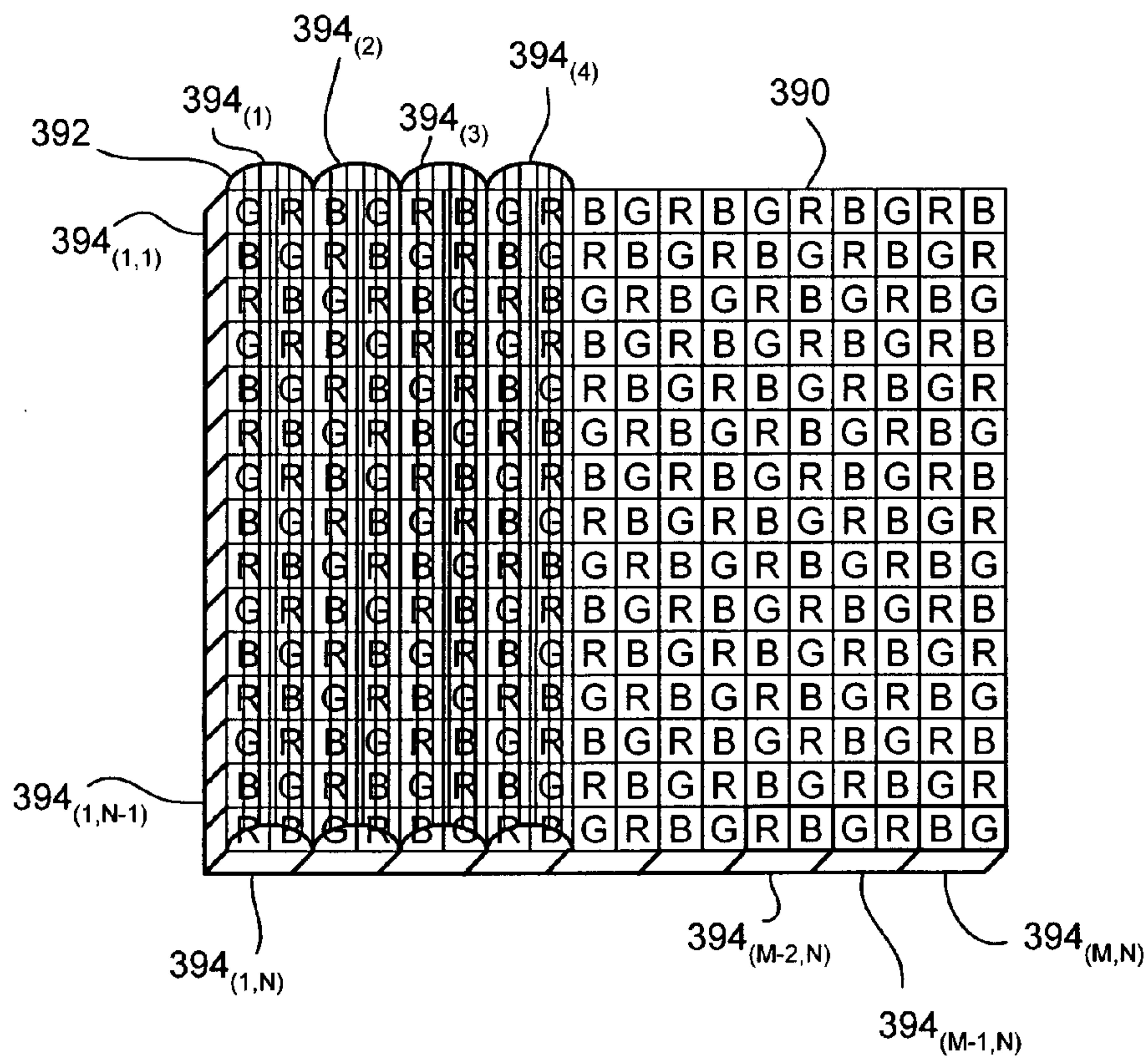


FIG. 6

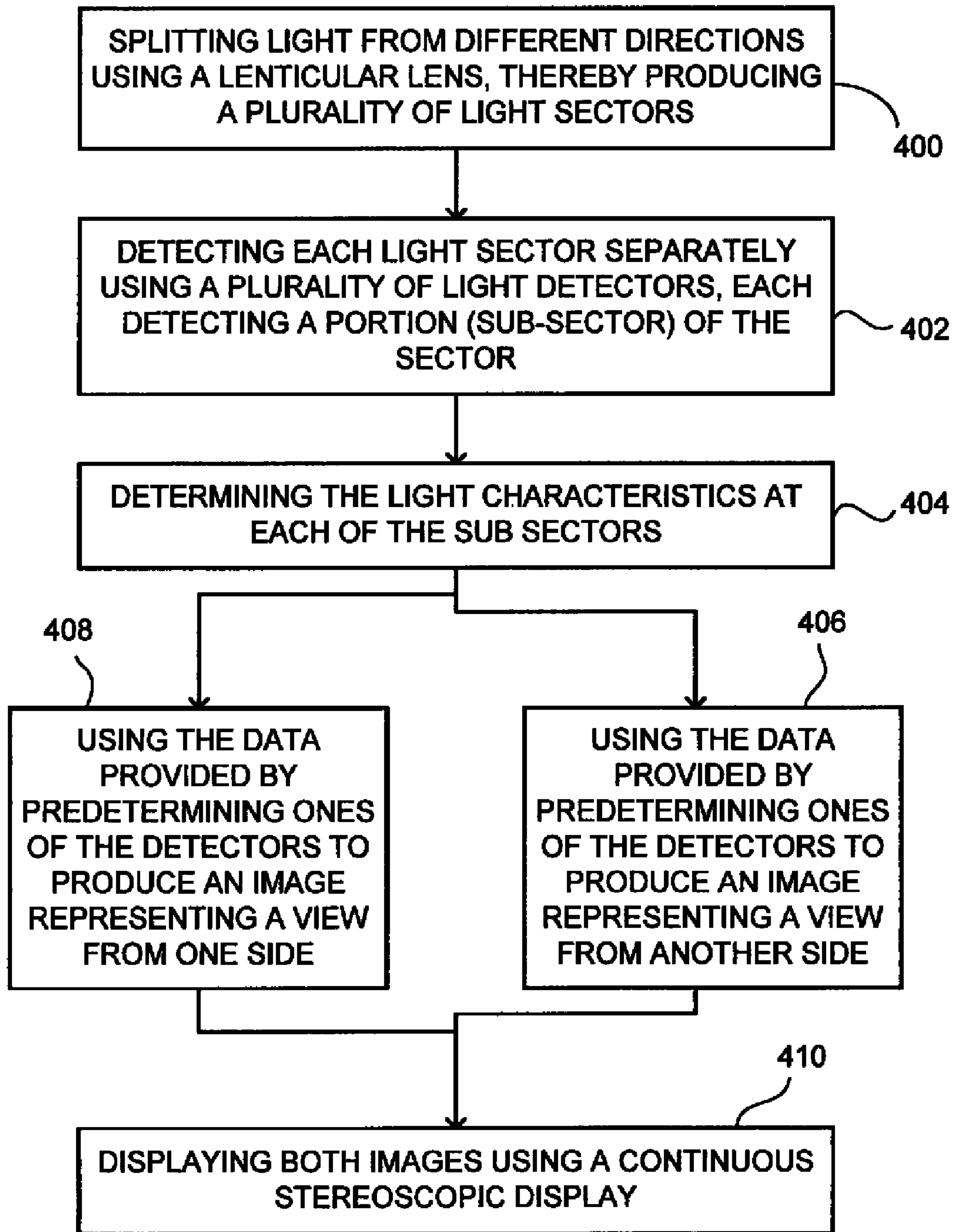


FIG. 7A

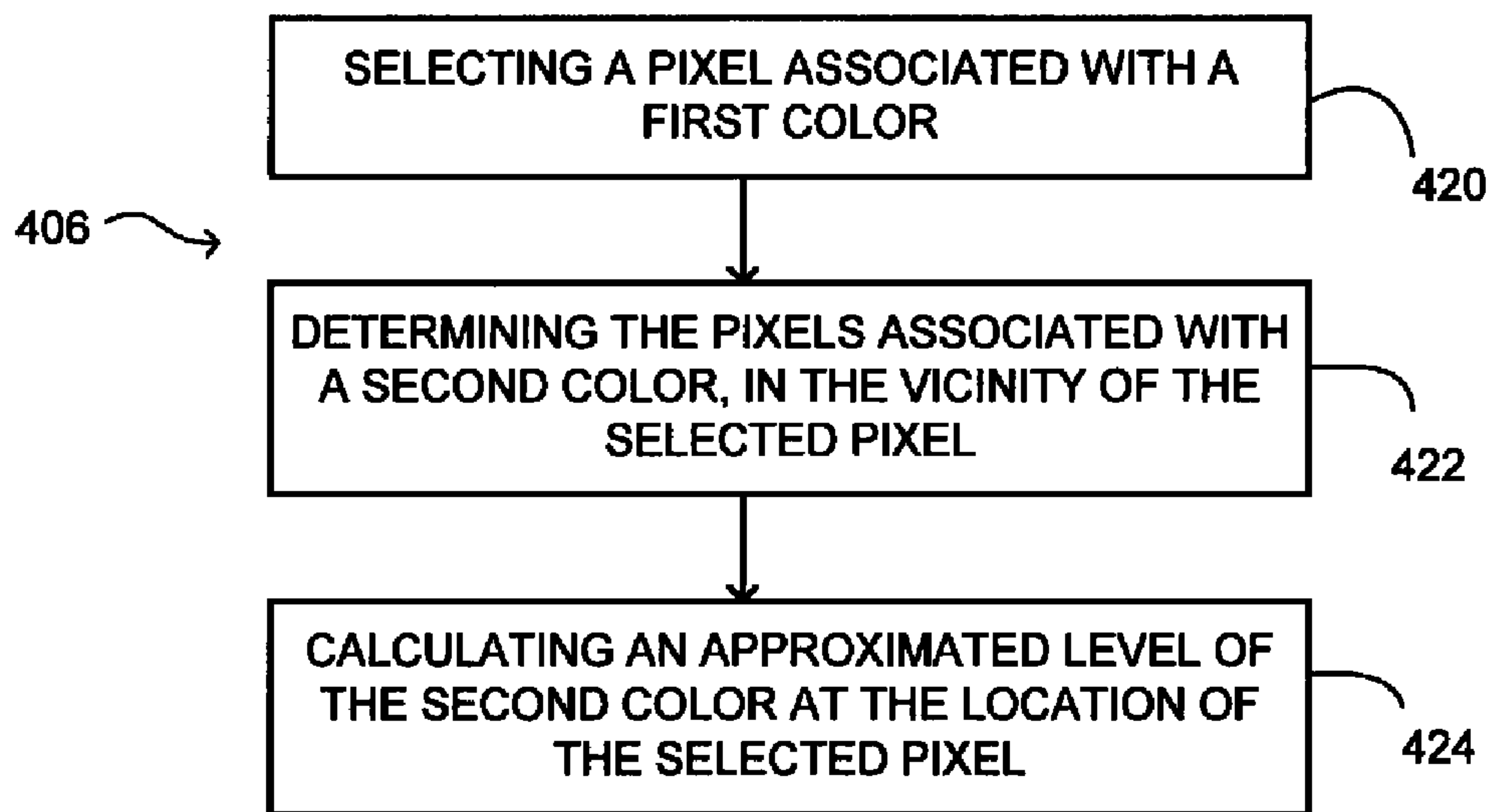


FIG. 7B

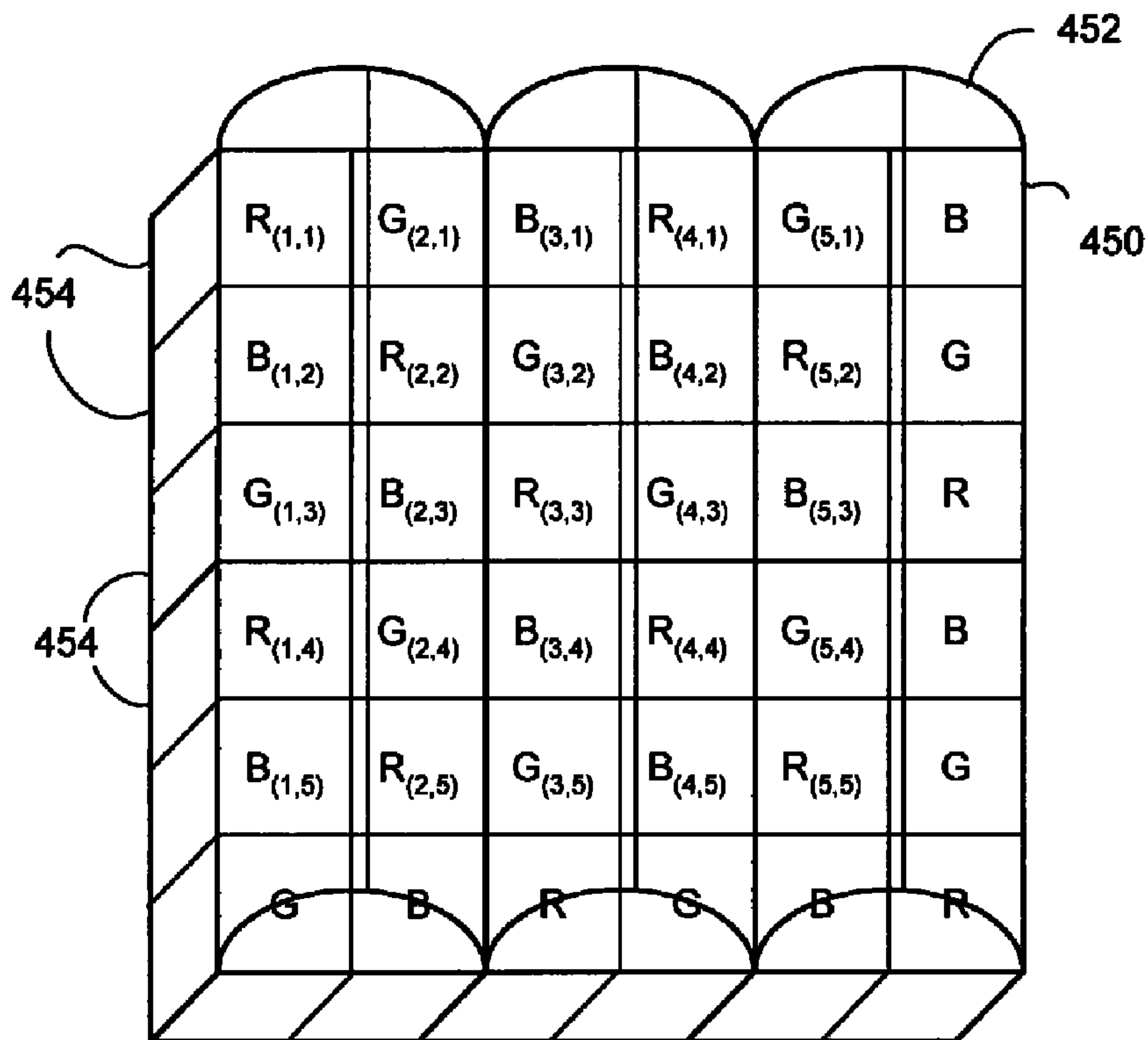
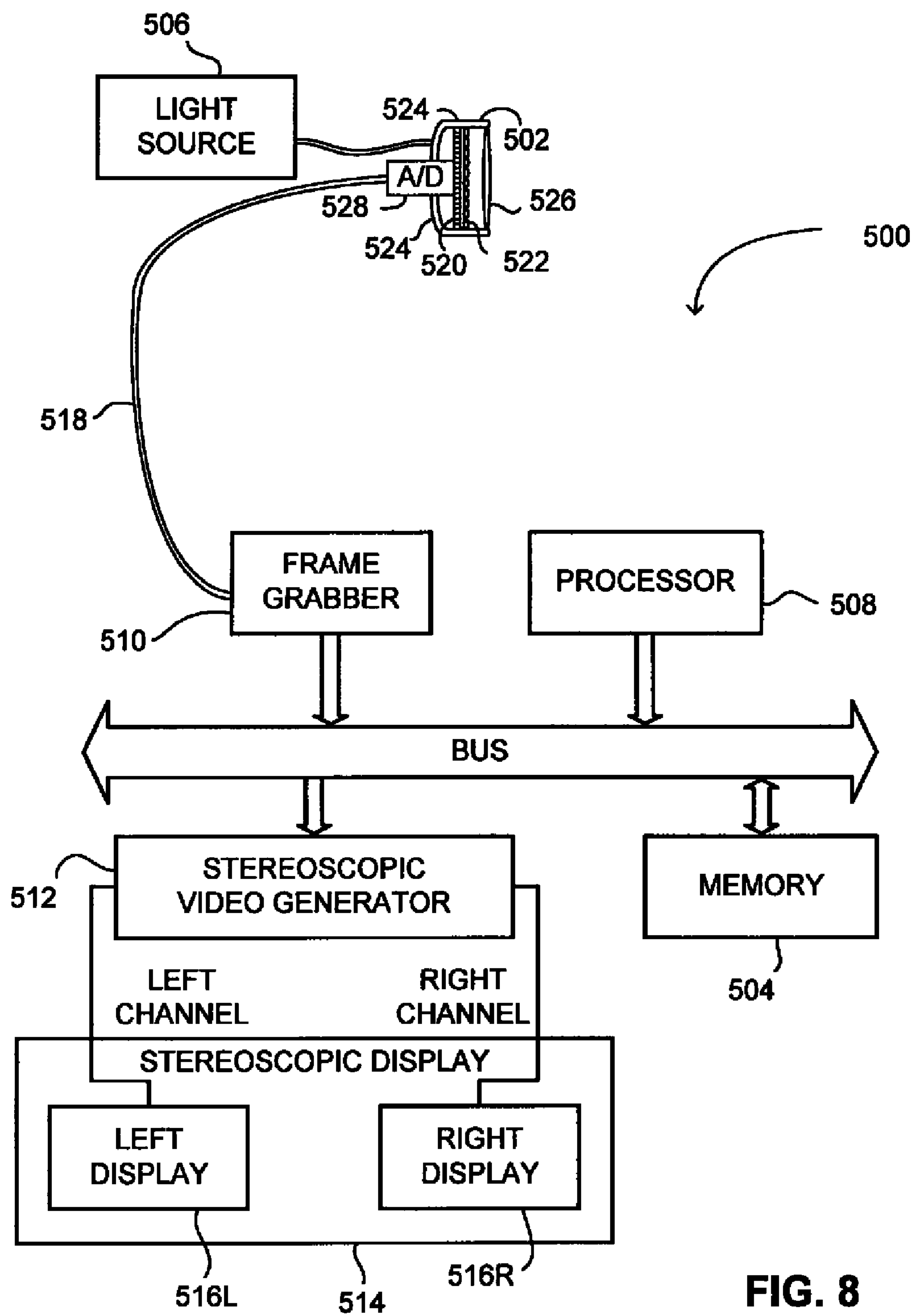


FIG. 7C



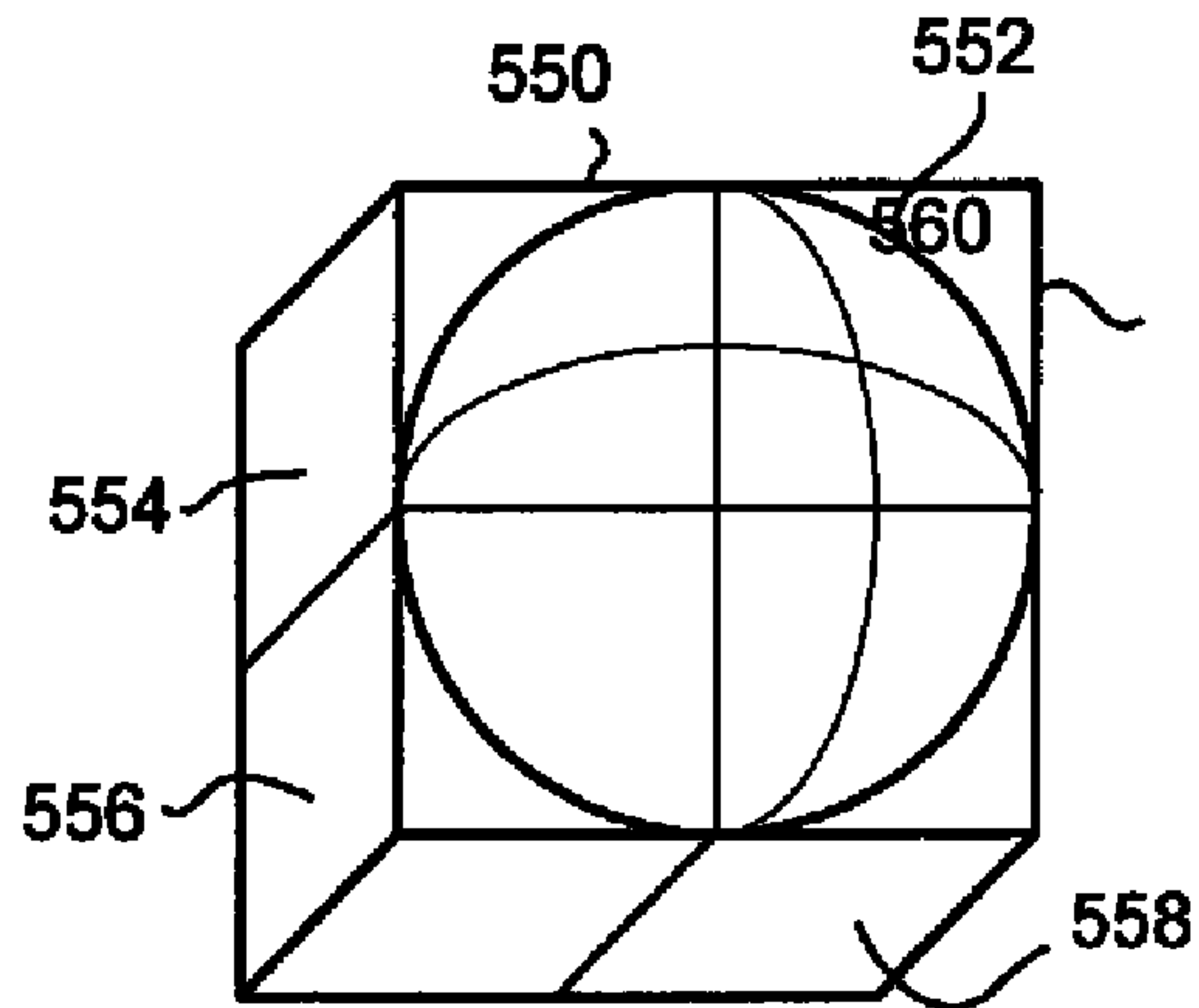


FIG. 9A

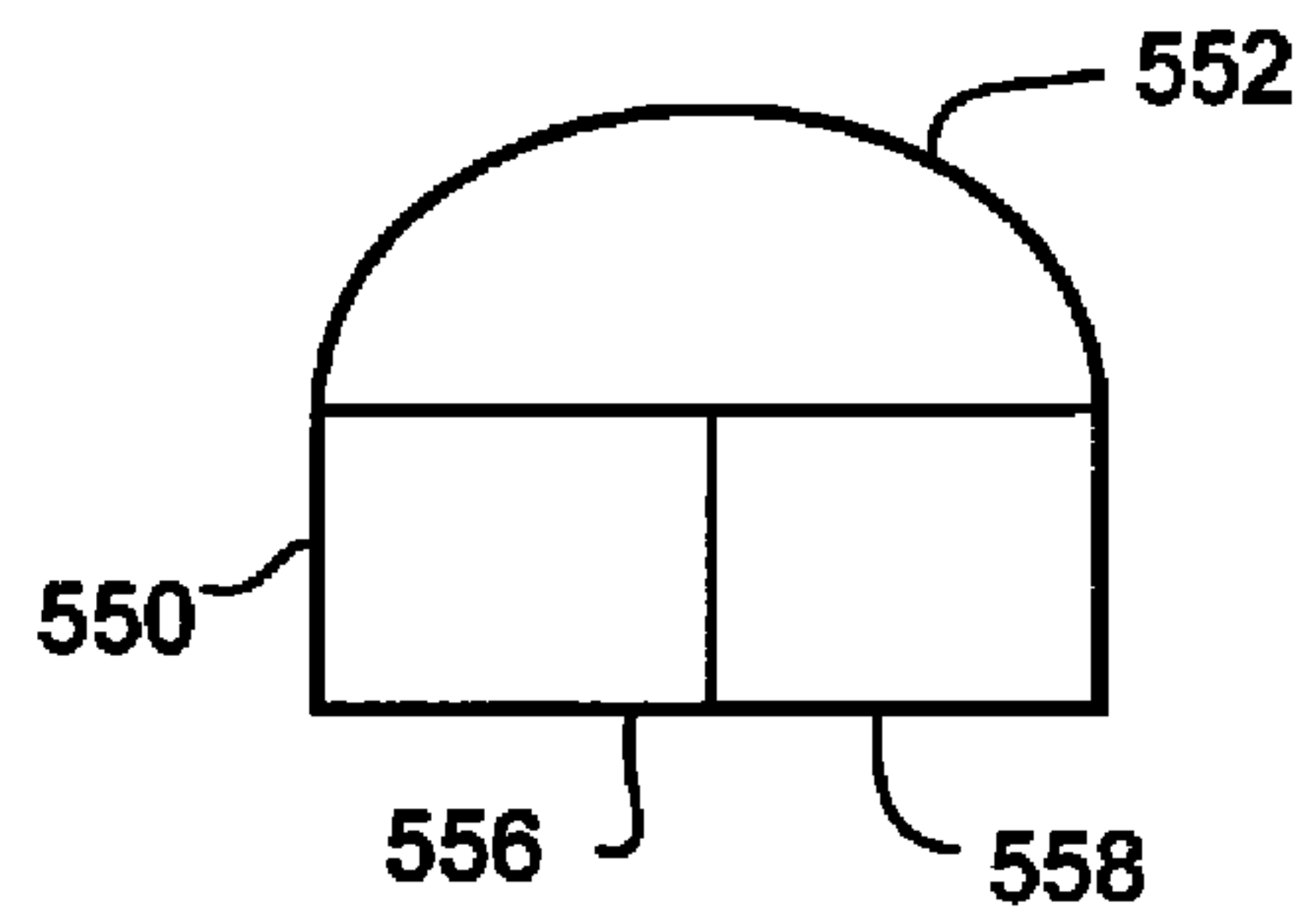


FIG. 9B

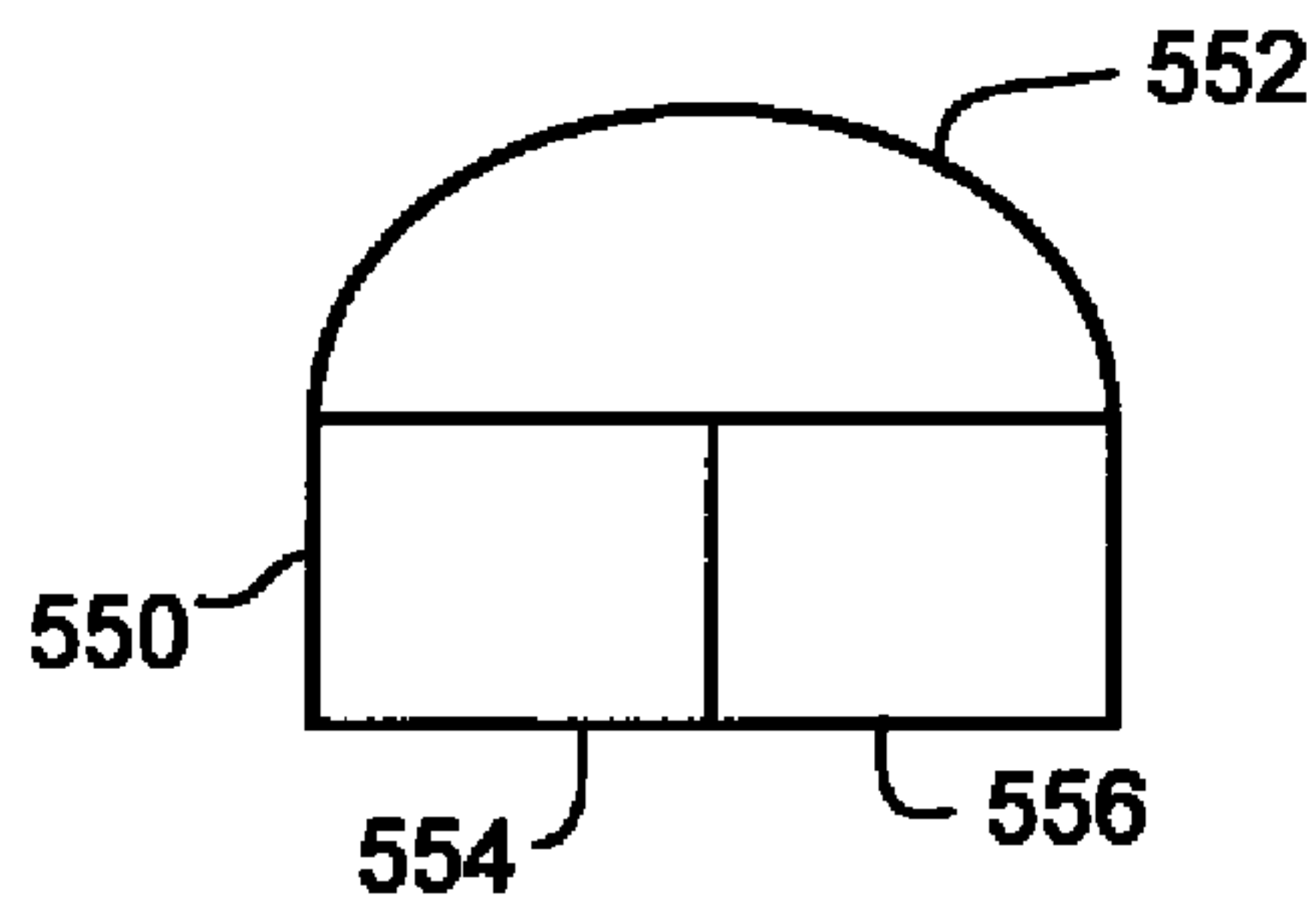


FIG. 9C

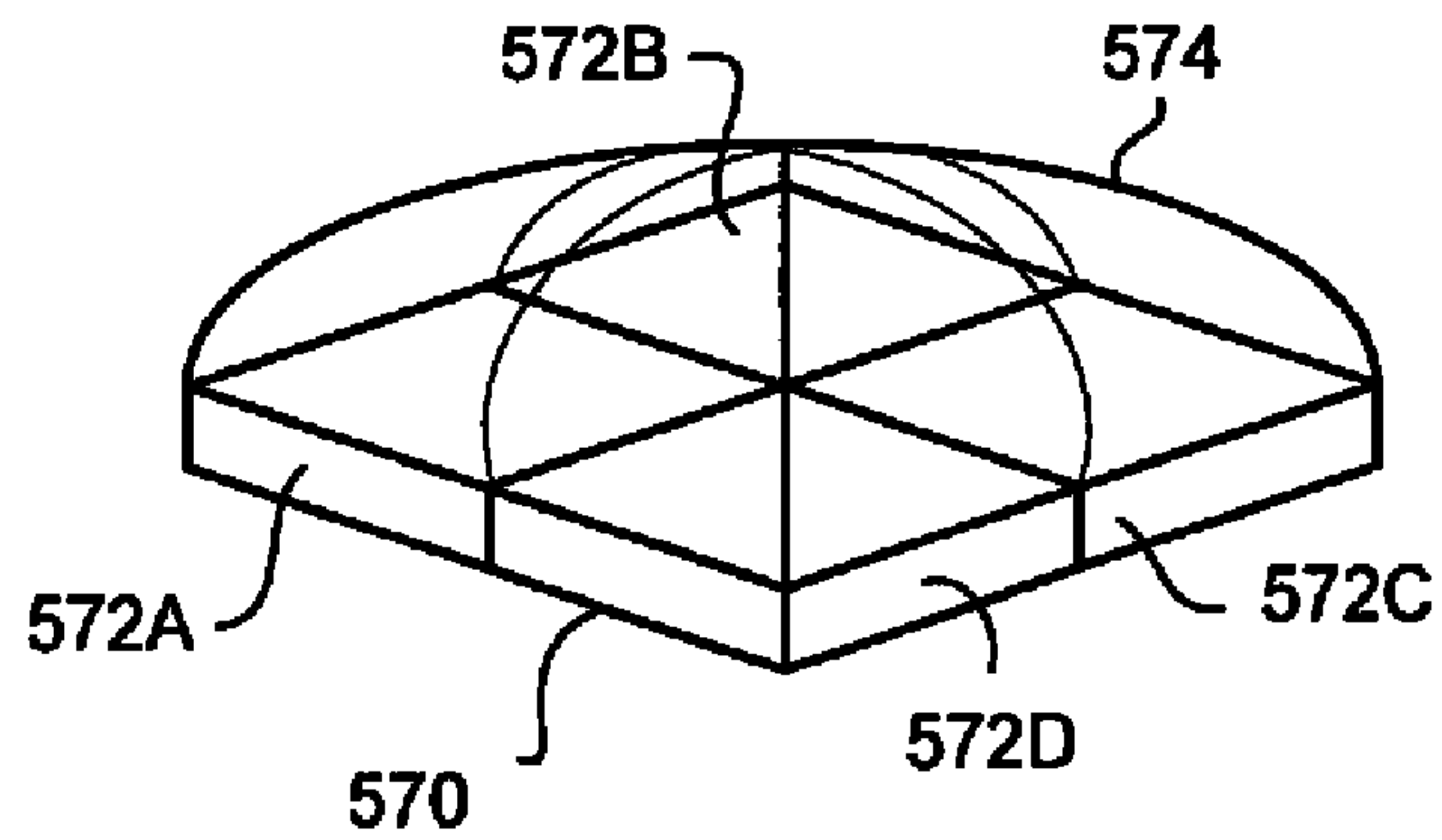


FIG. 10

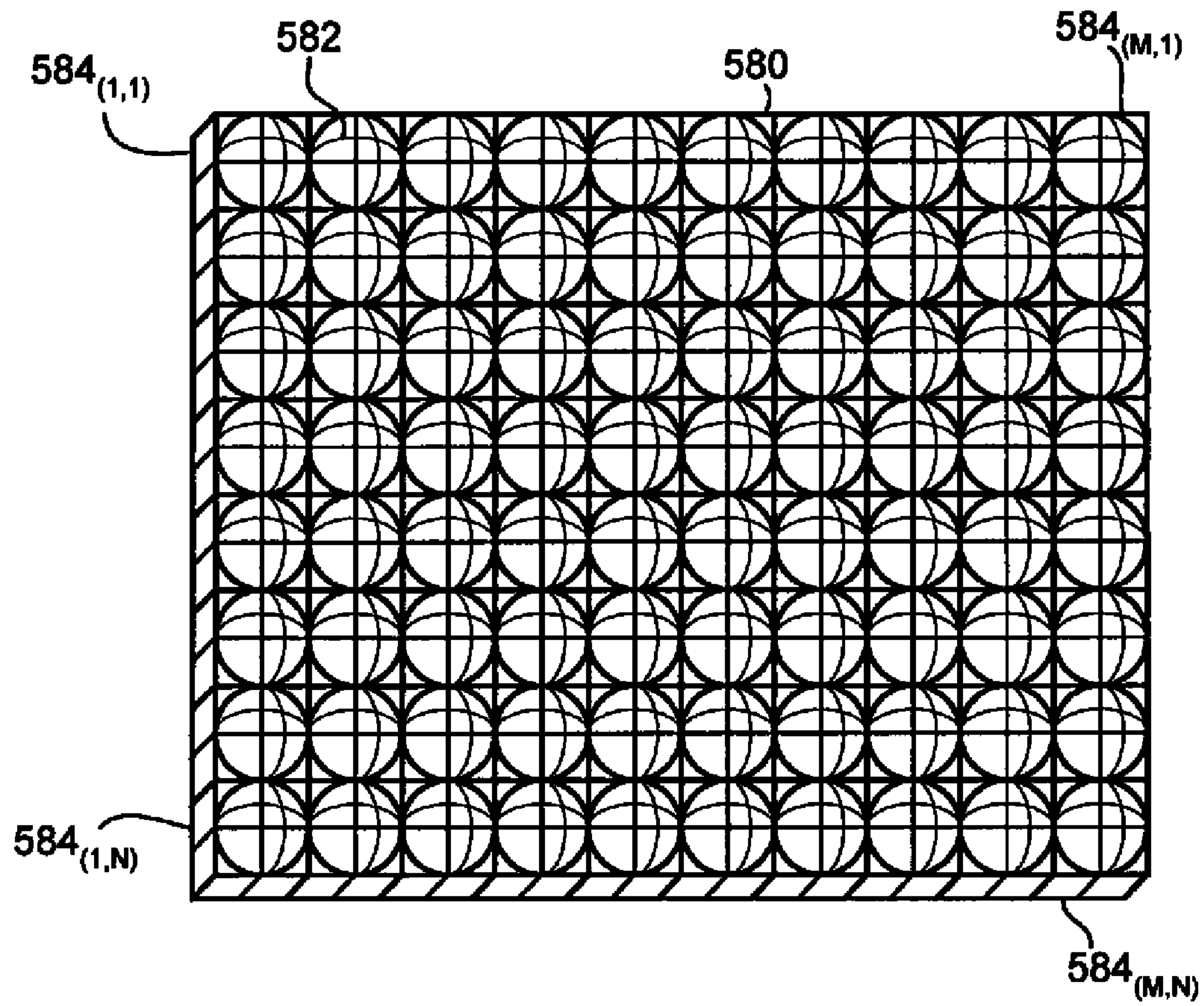


FIG. 11

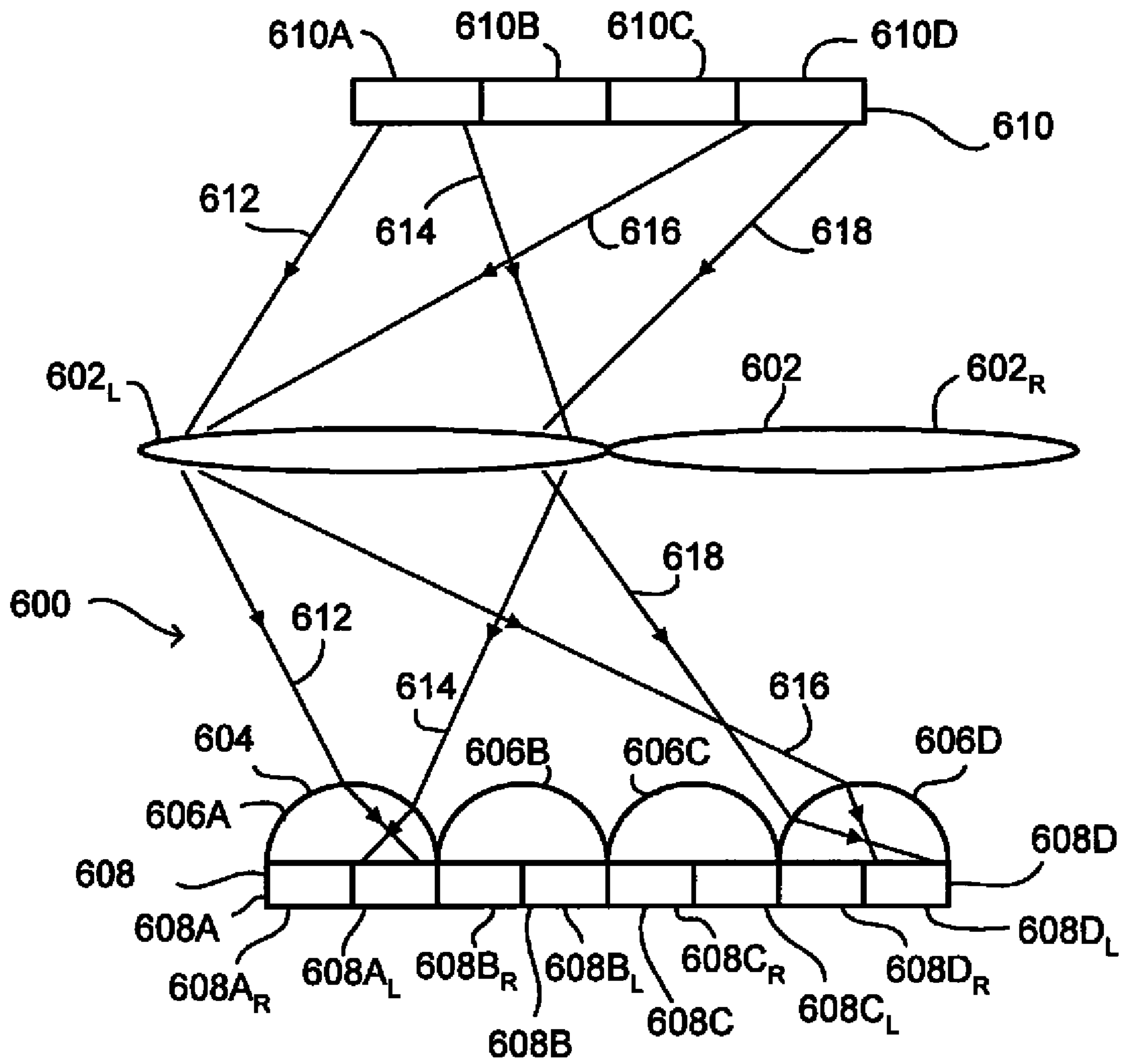


FIG. 12A

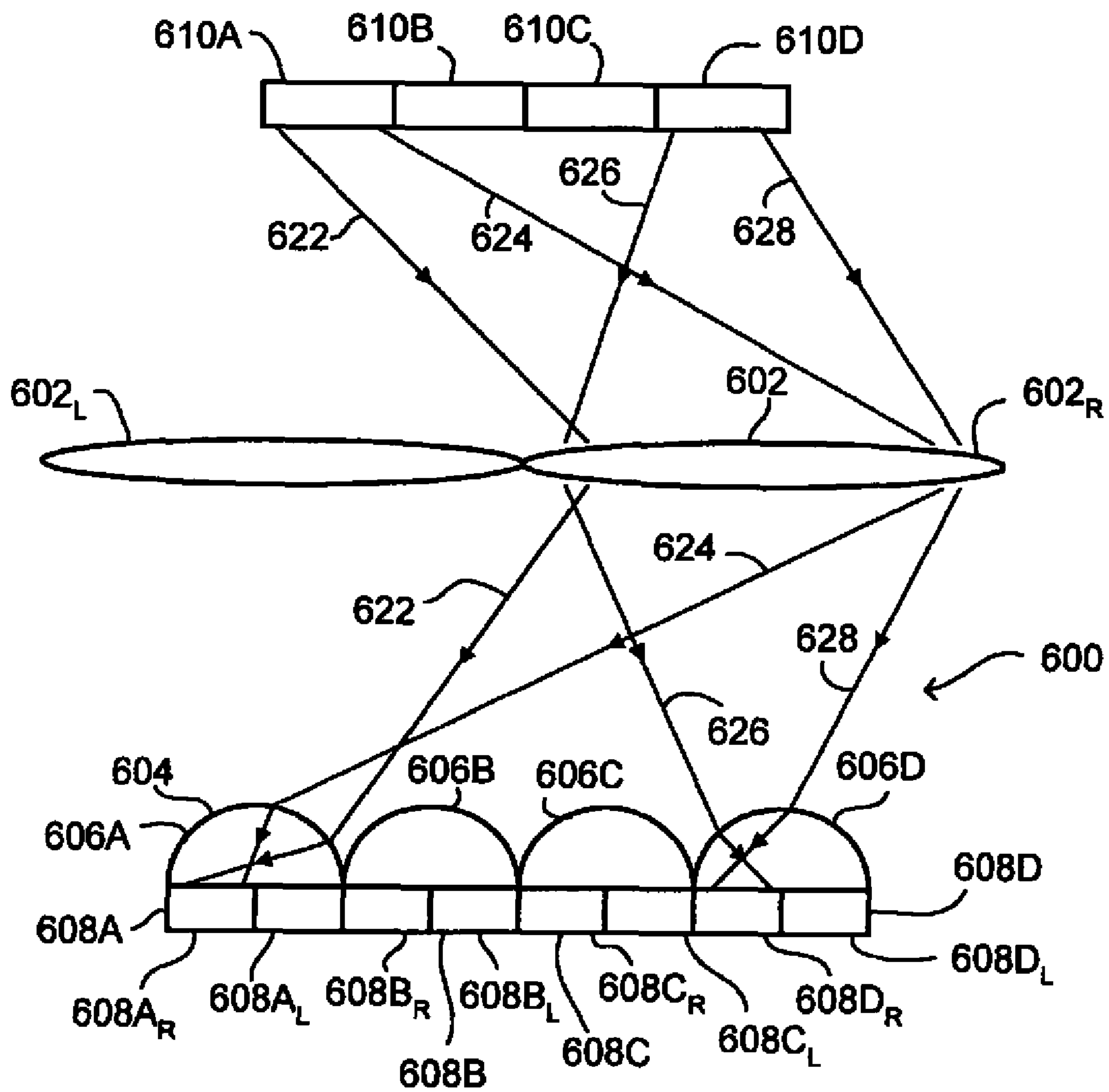


FIG. 12B

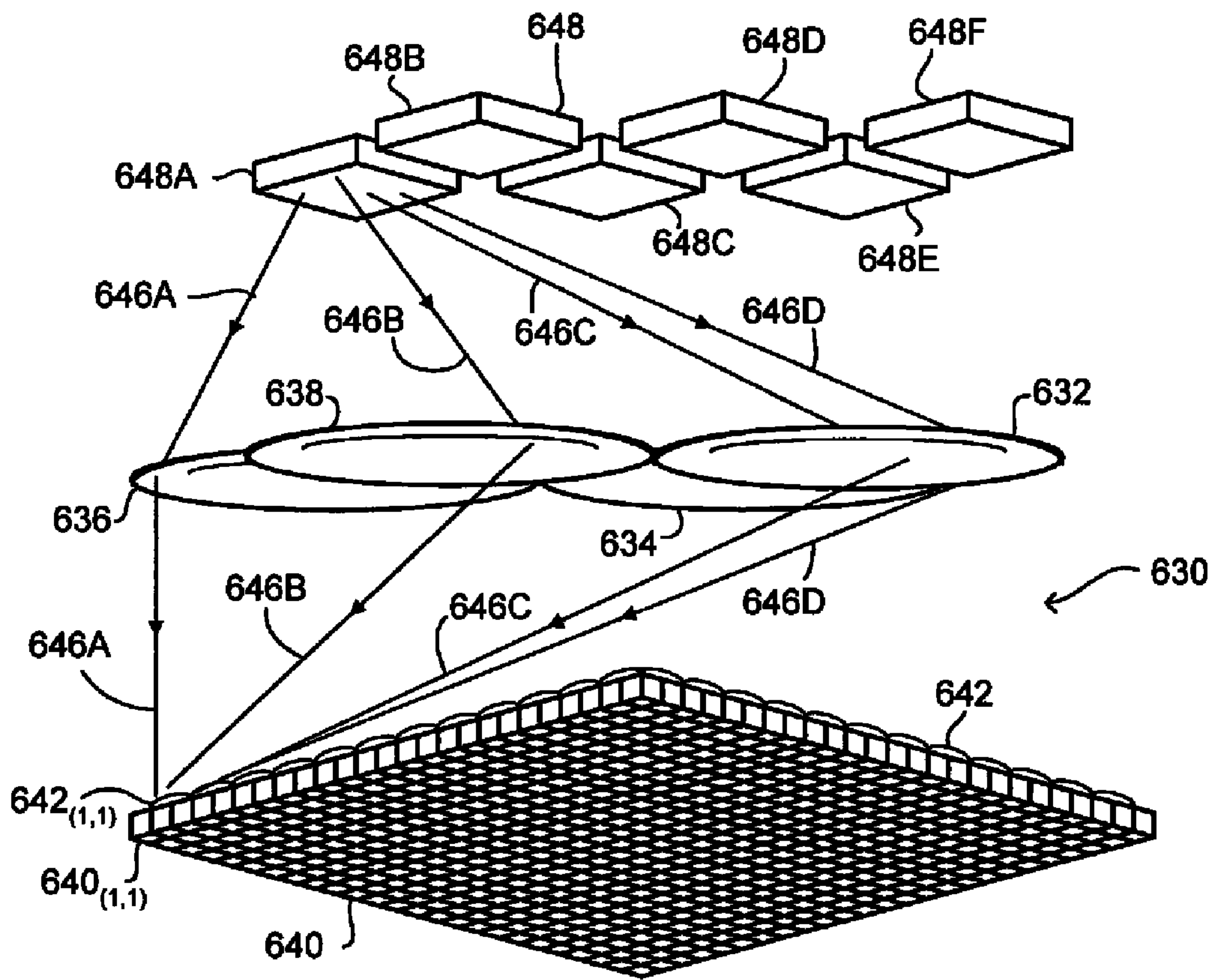


FIG. 13

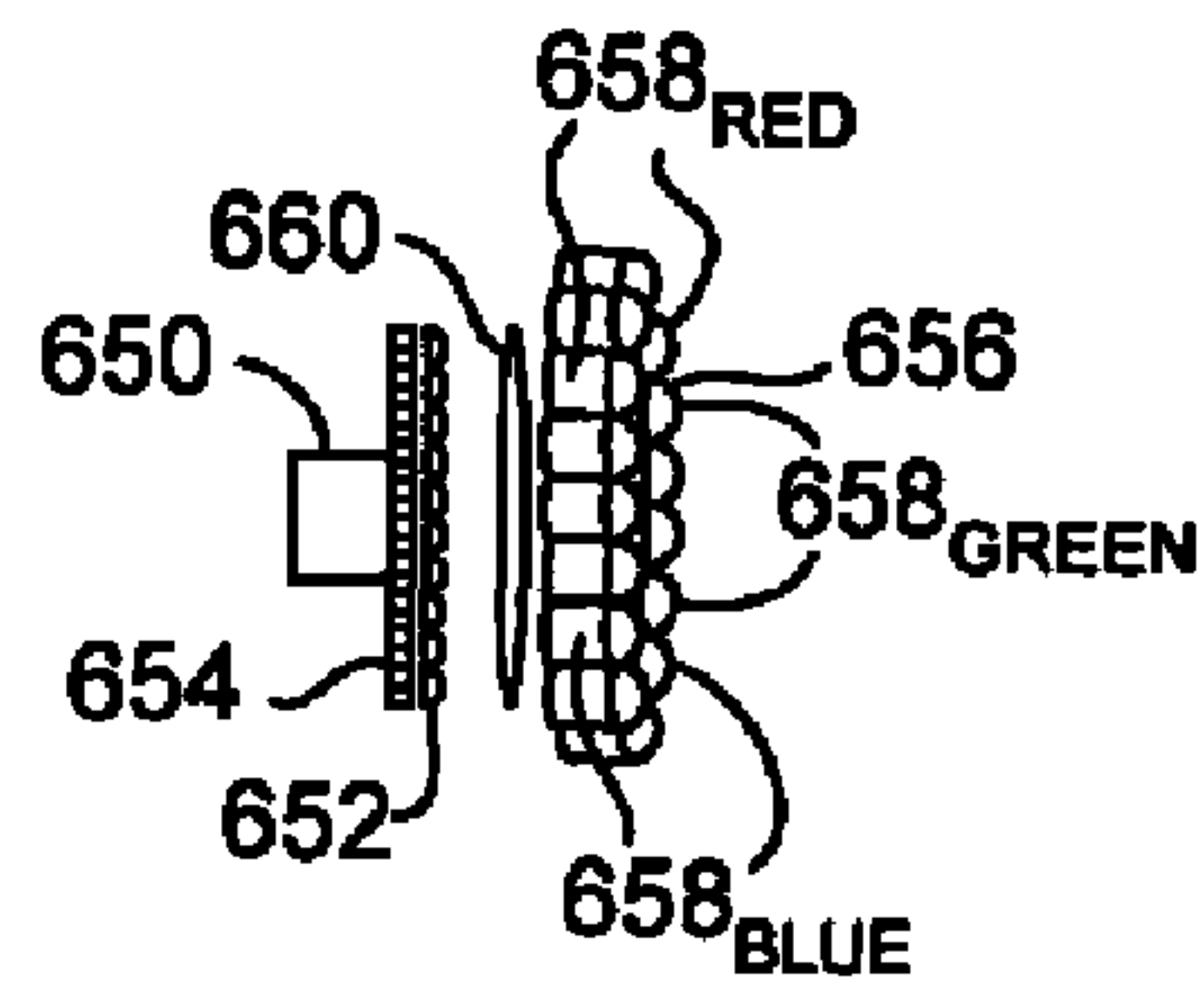


FIG. 14A

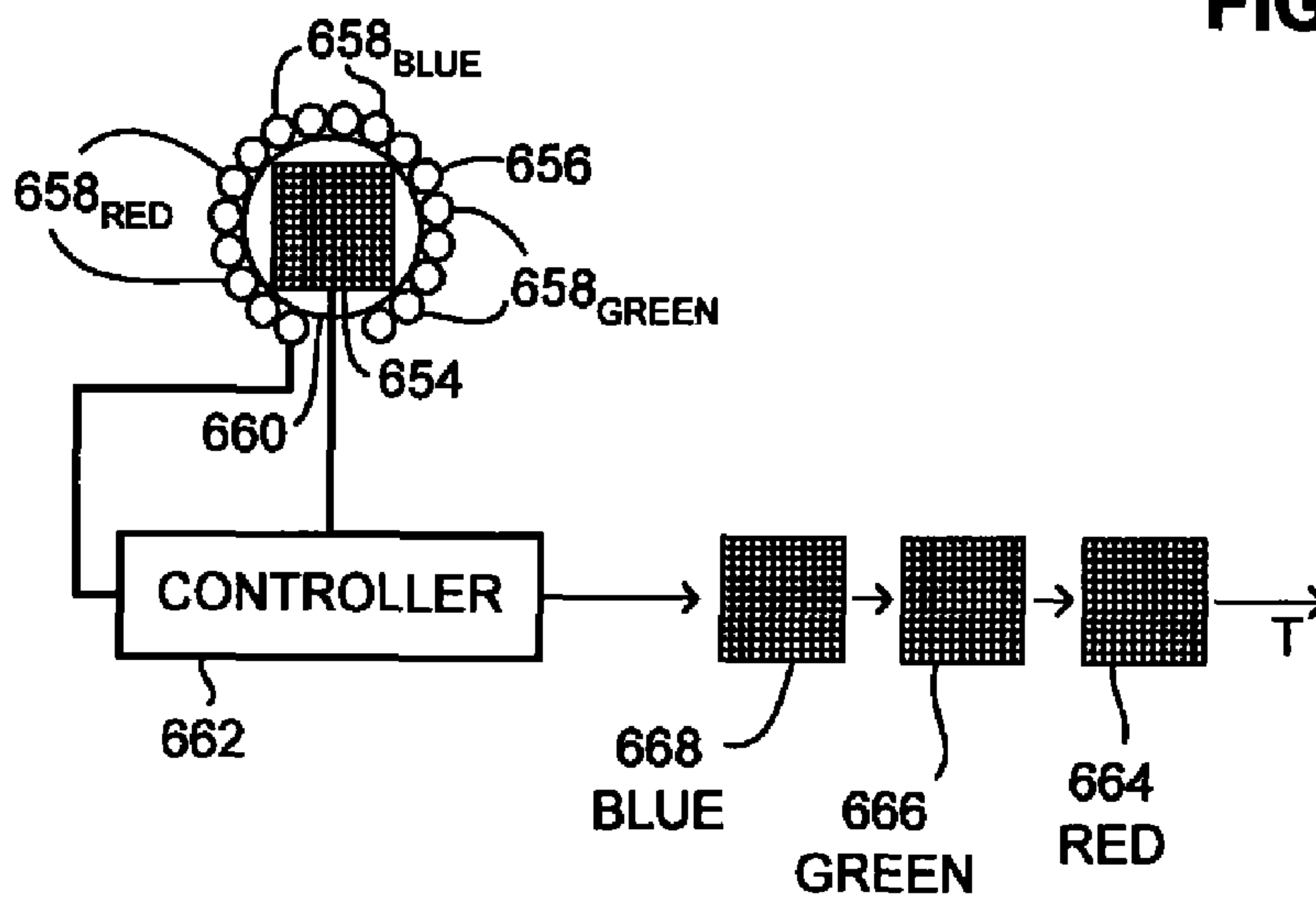


FIG. 14B

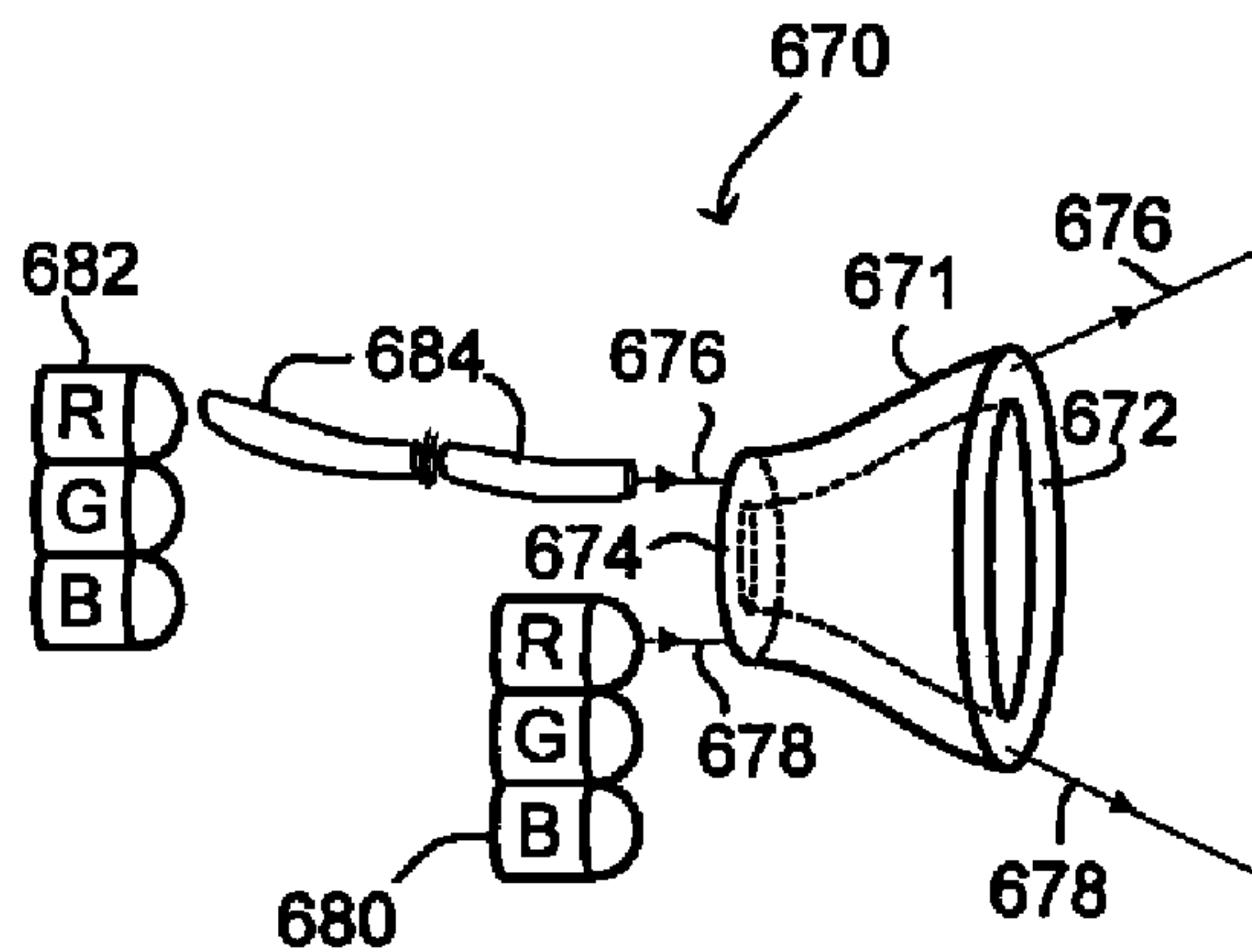


FIG. 15

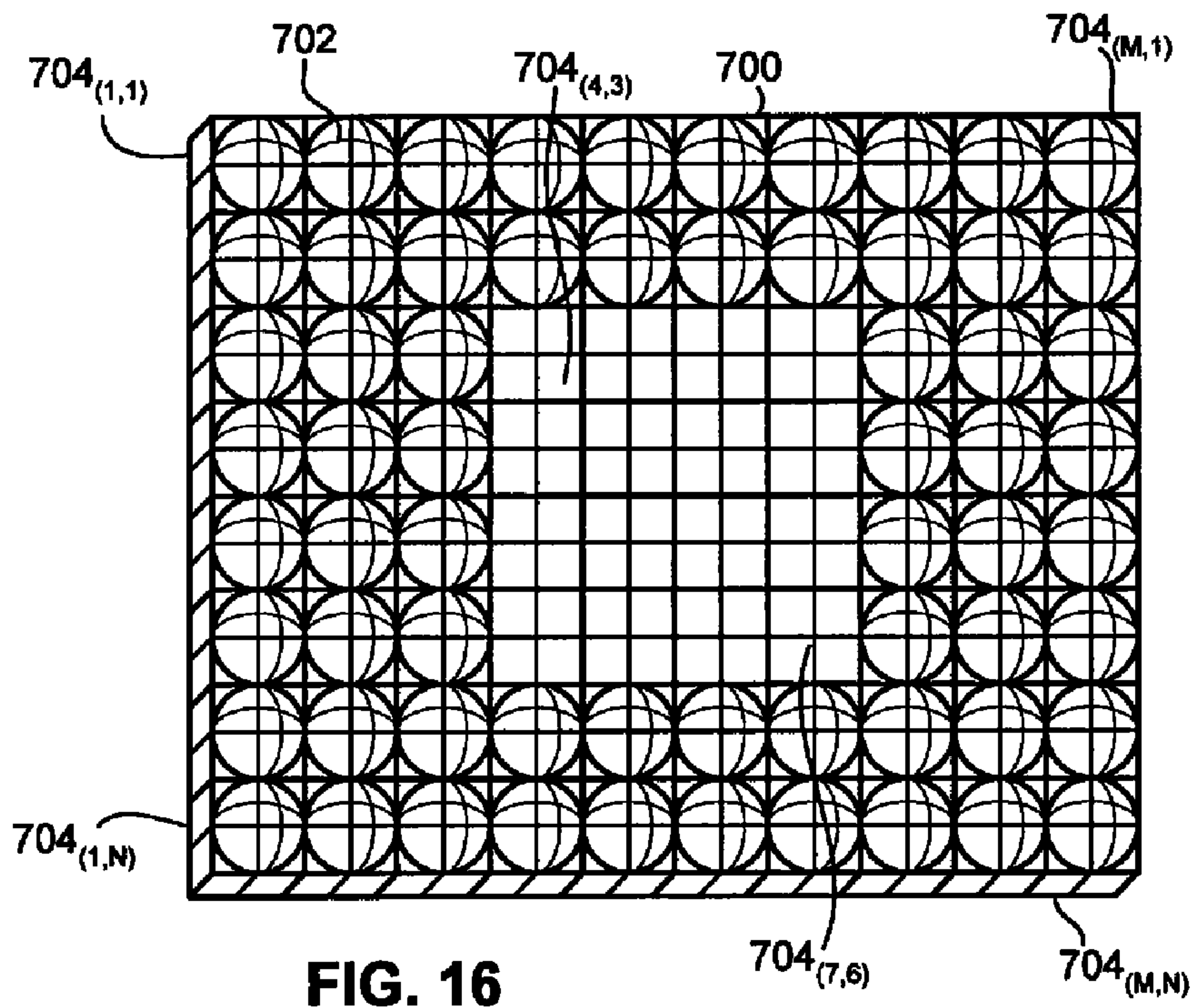


FIG. 16

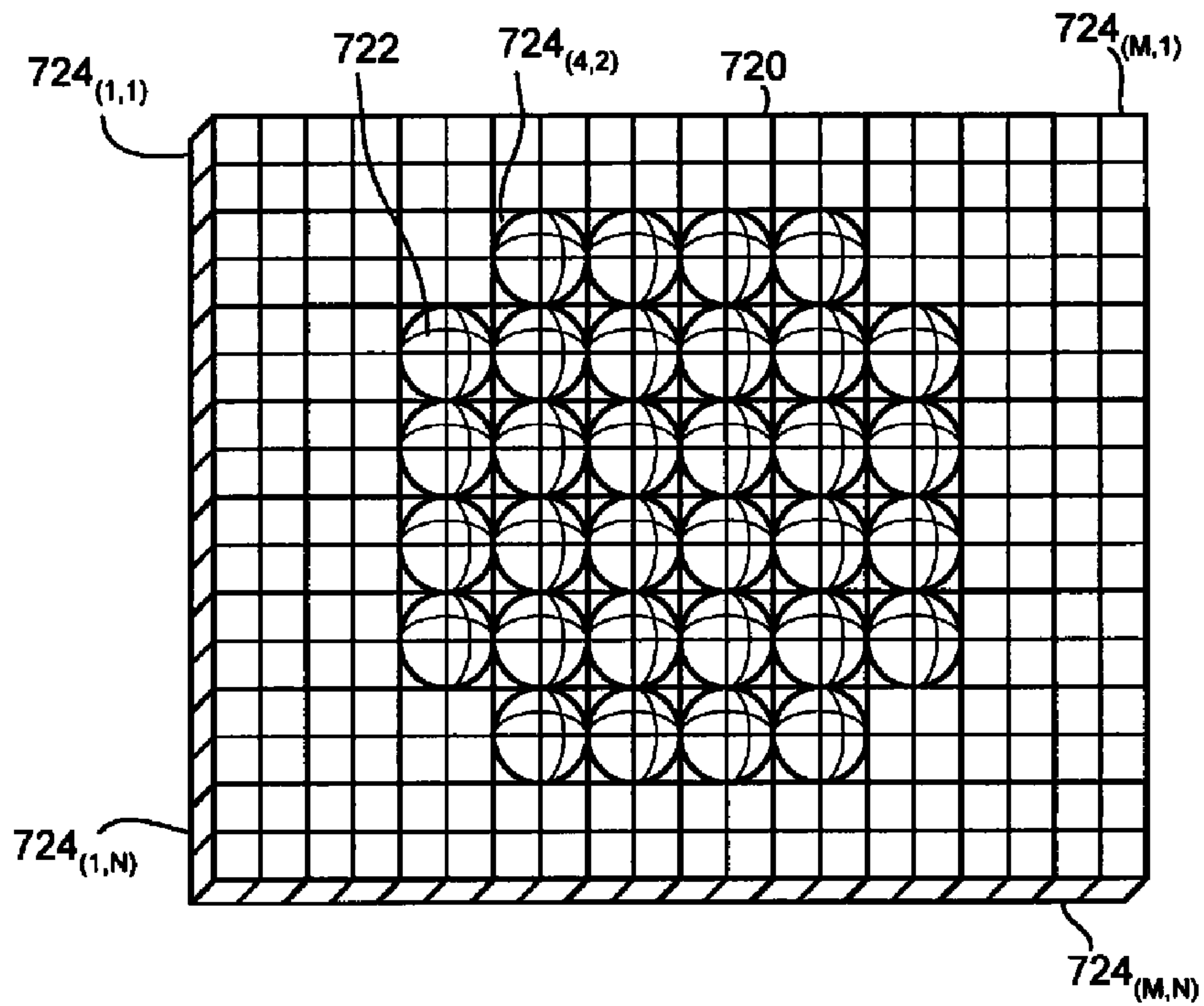


FIG. 17

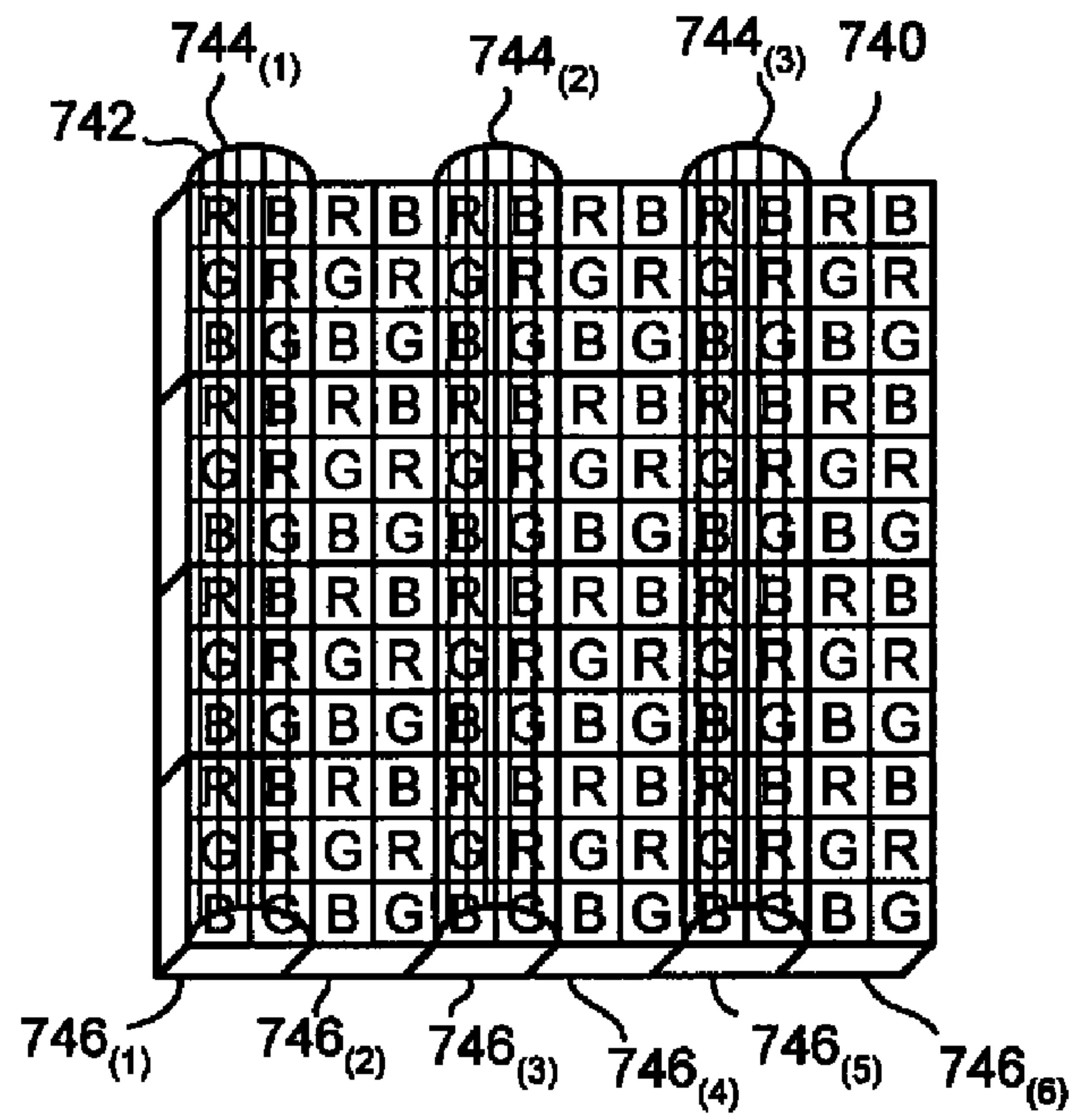


FIG. 18

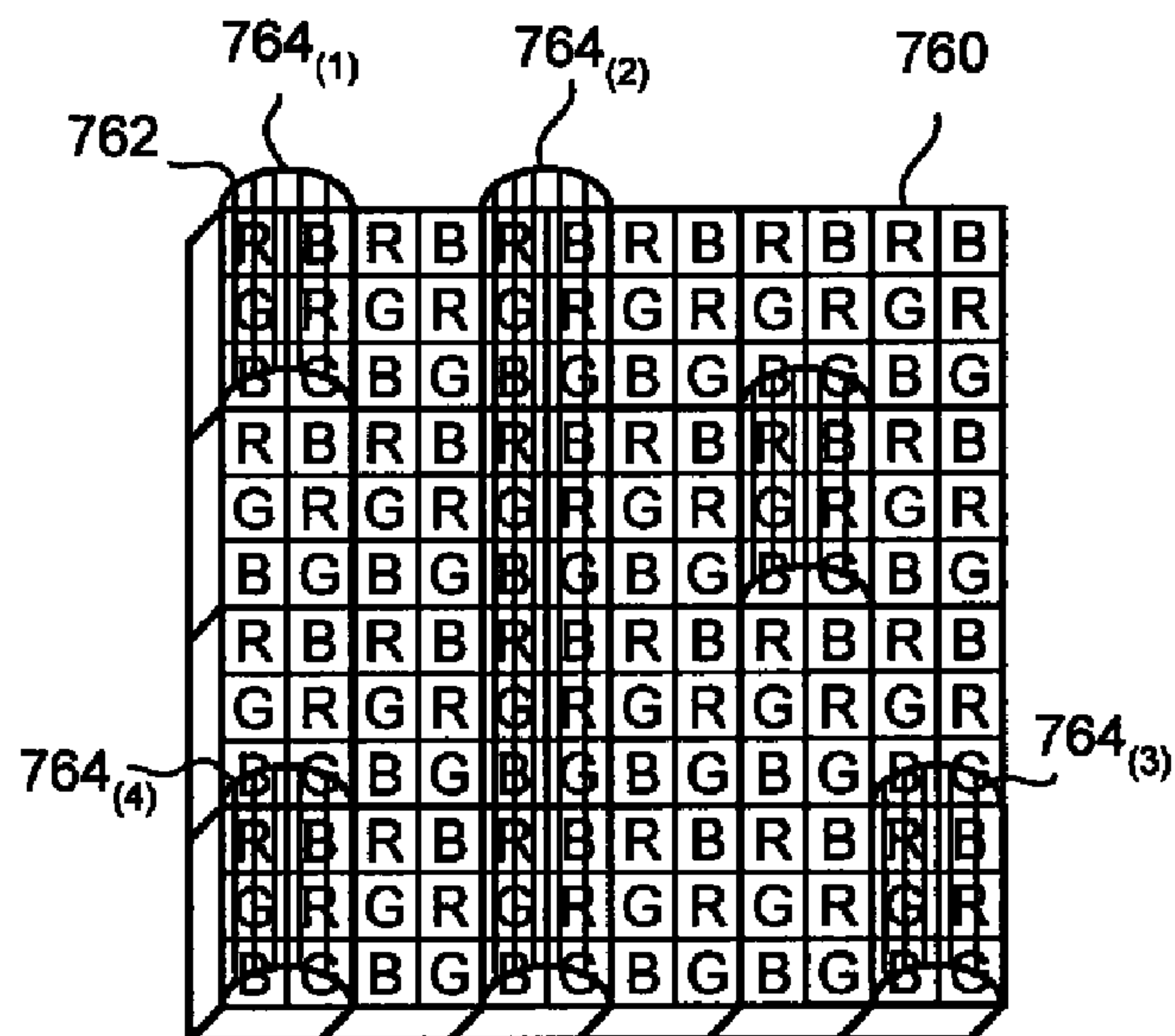


FIG. 19

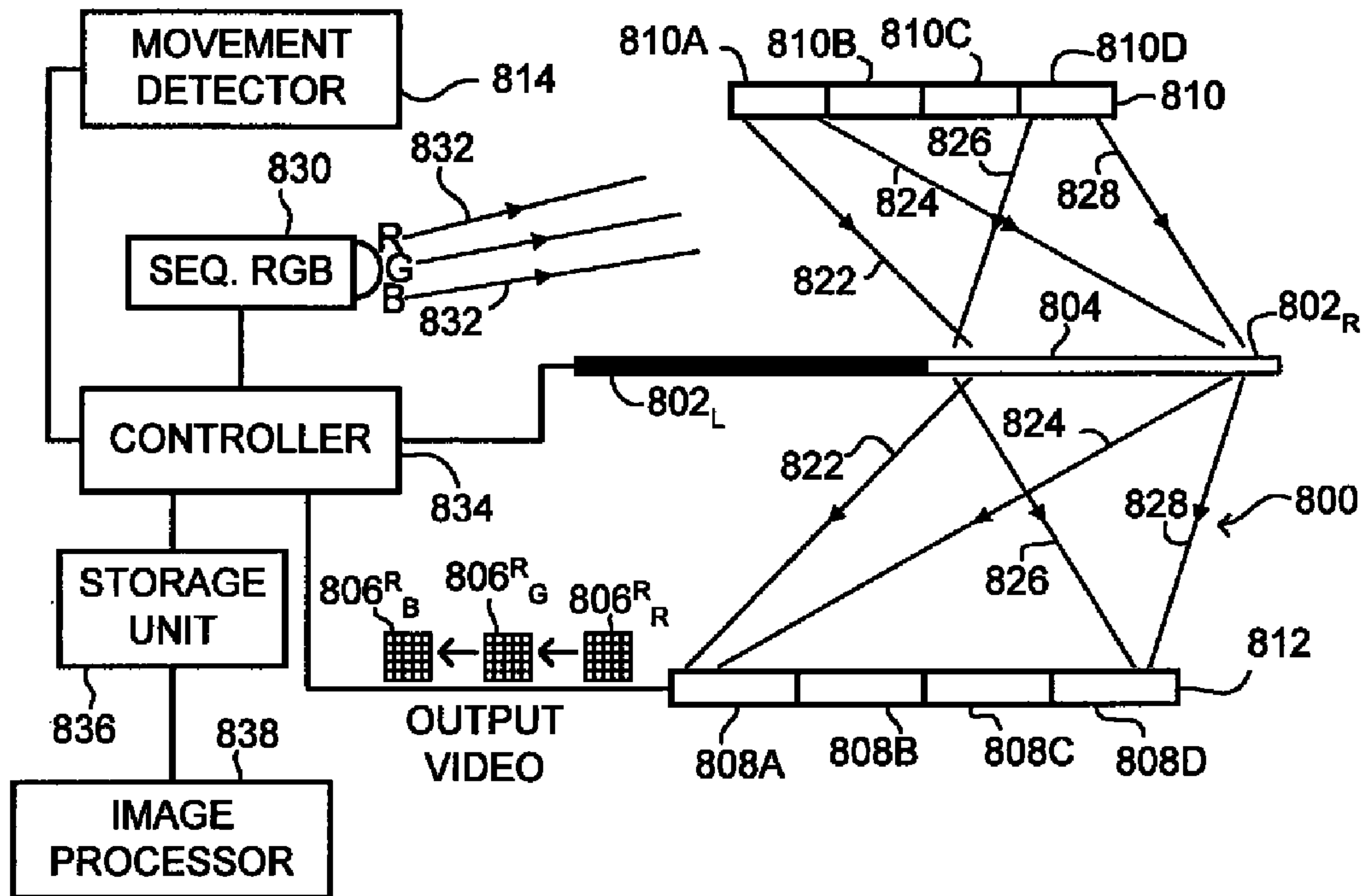


FIG. 20A

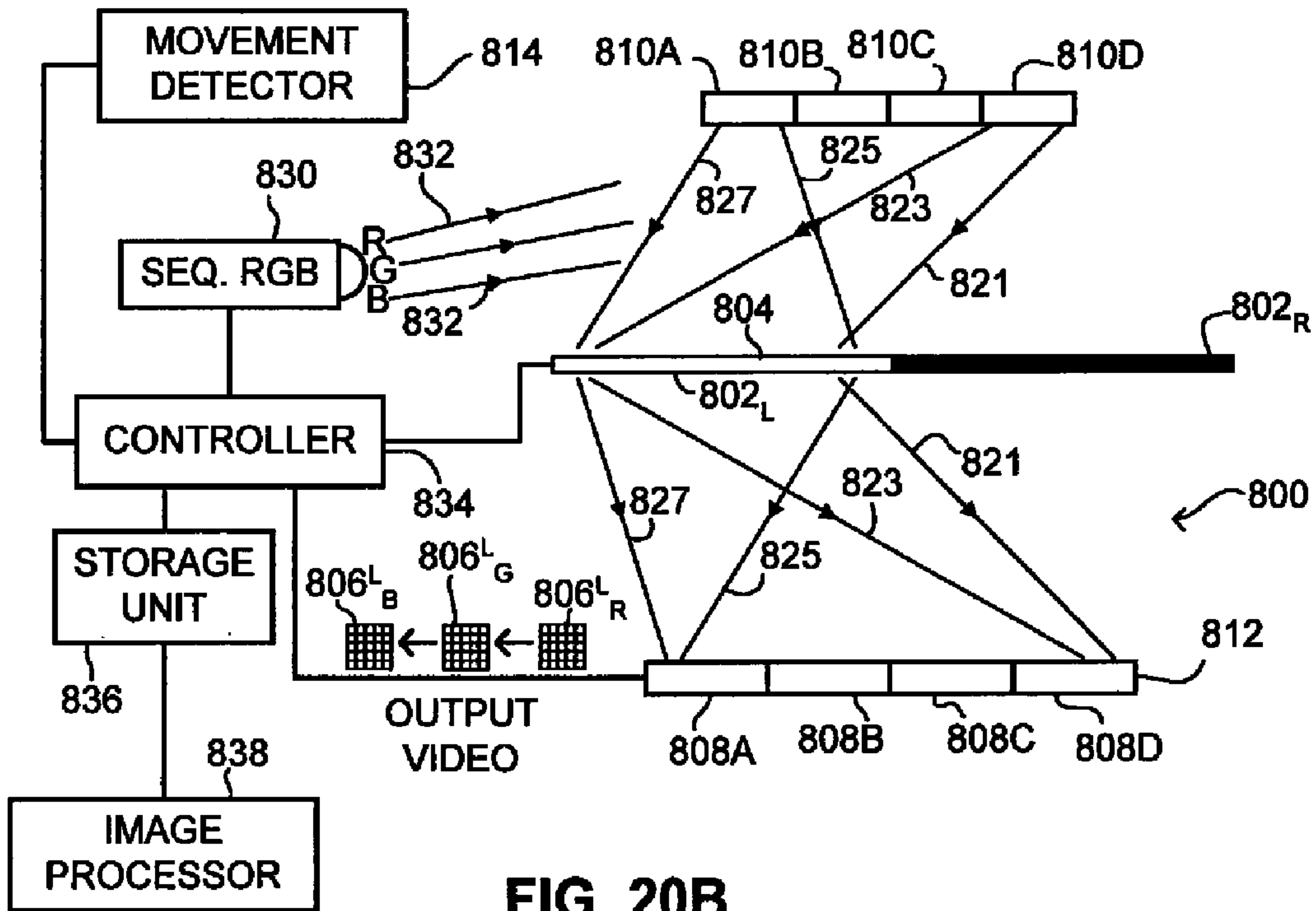
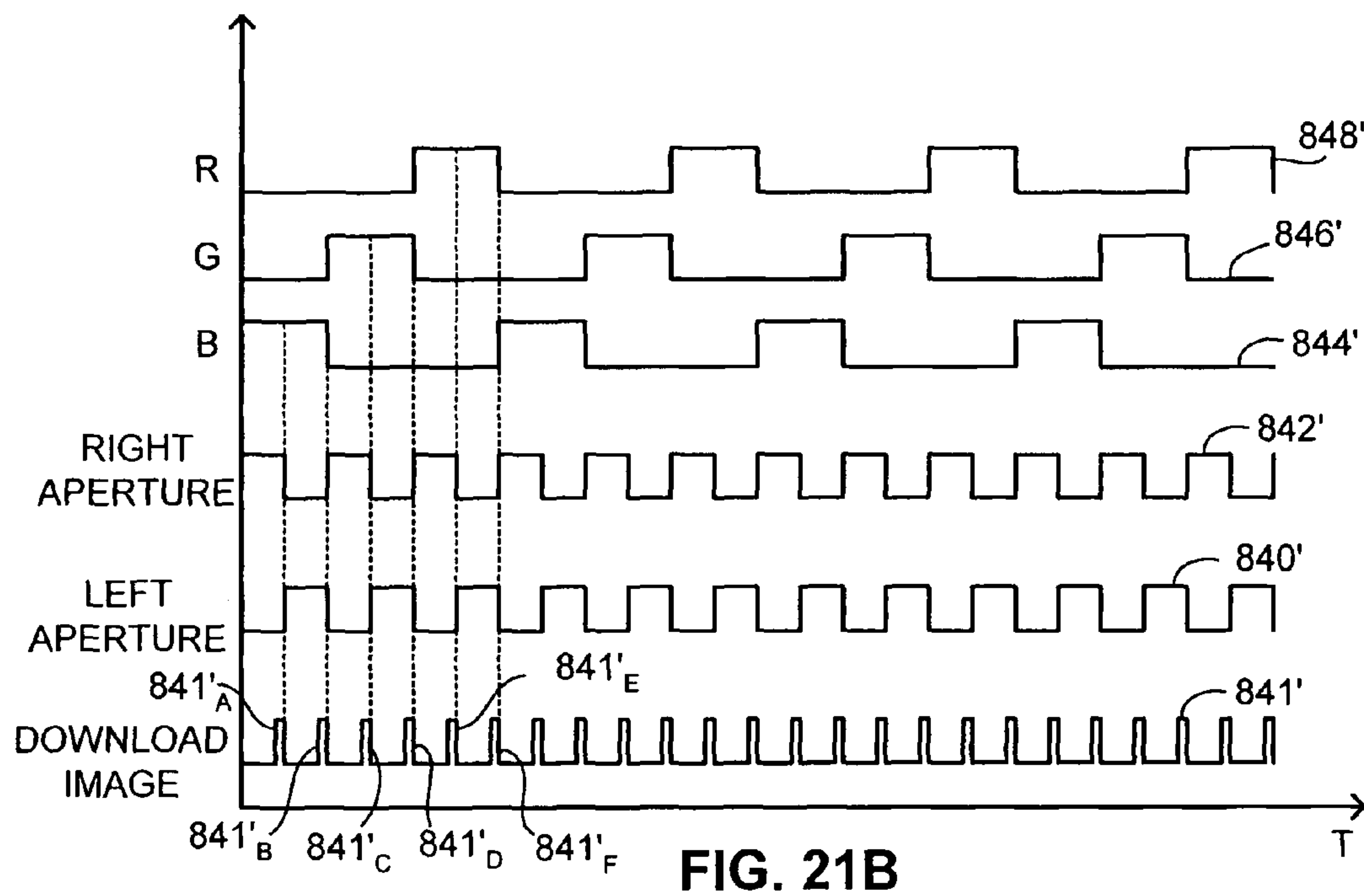
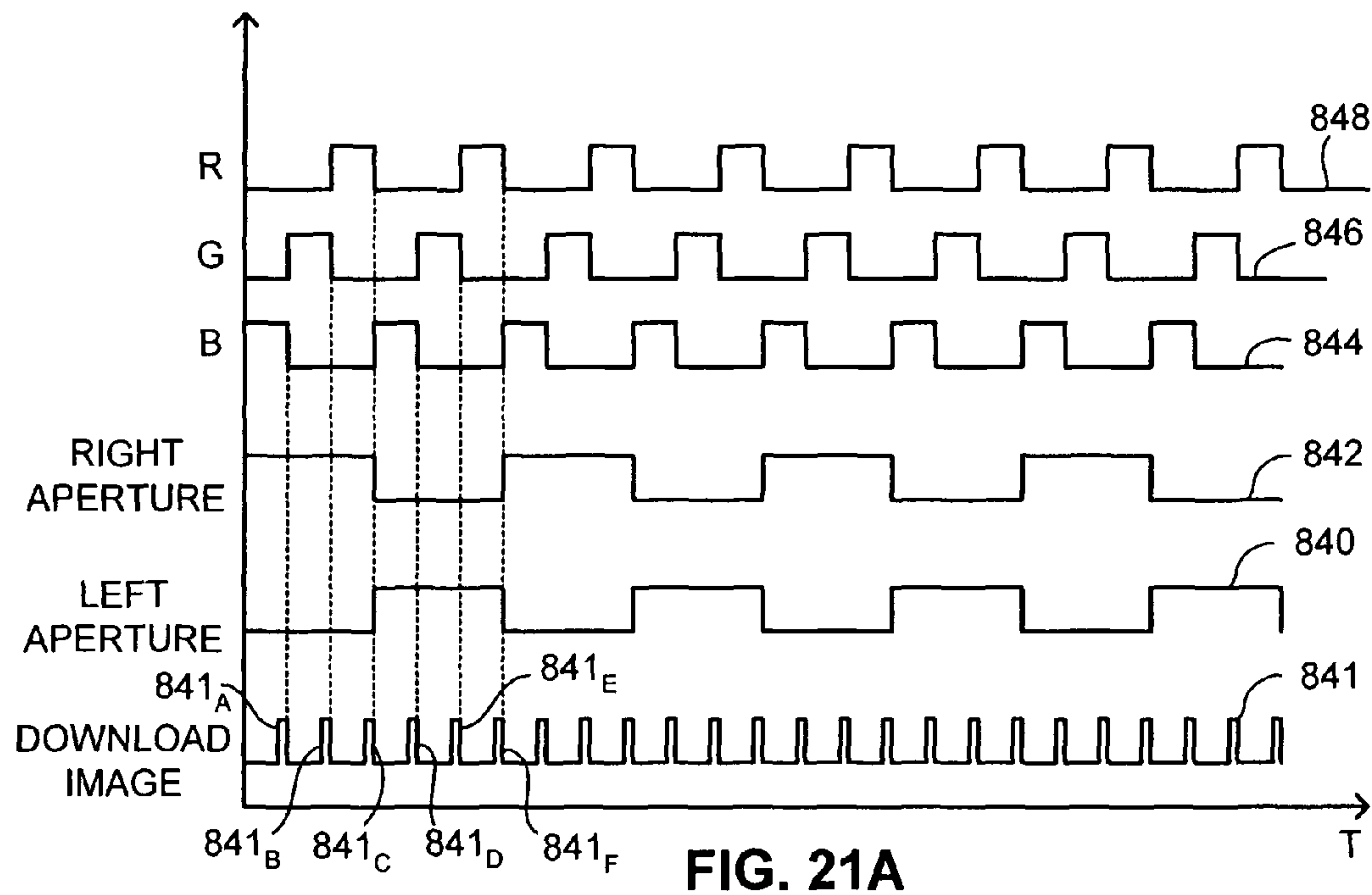
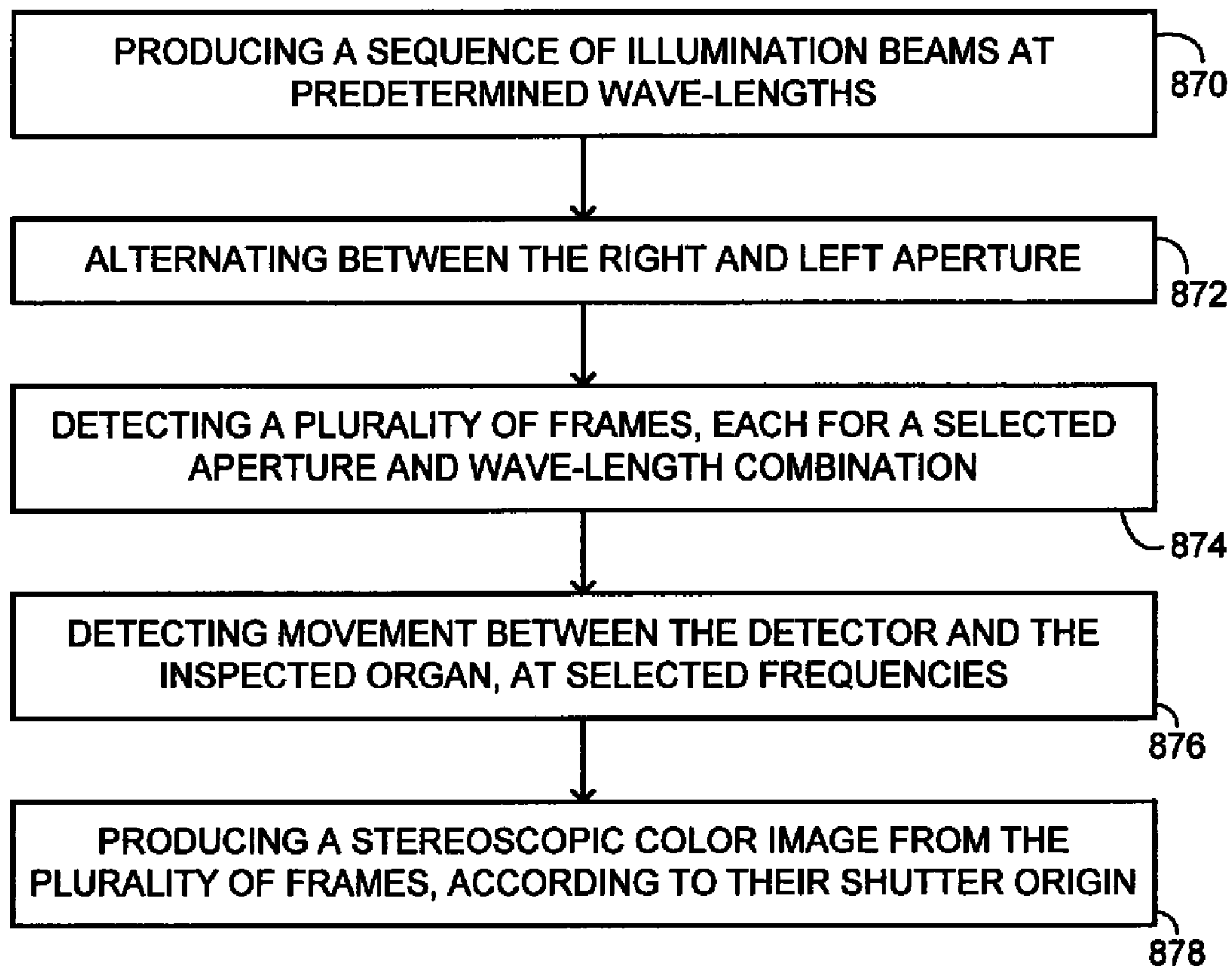


FIG. 20B



**FIG. 22**

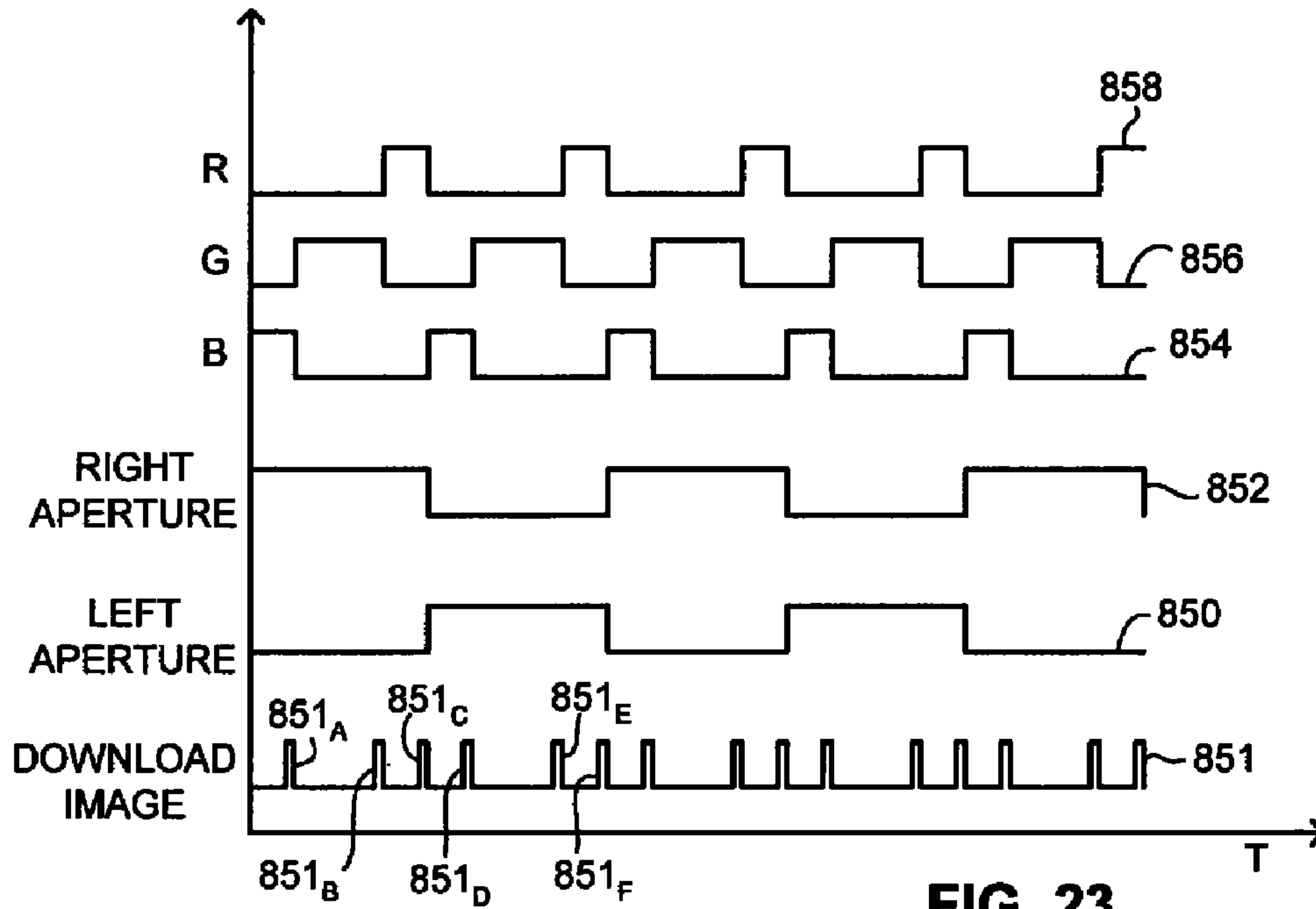


FIG. 23

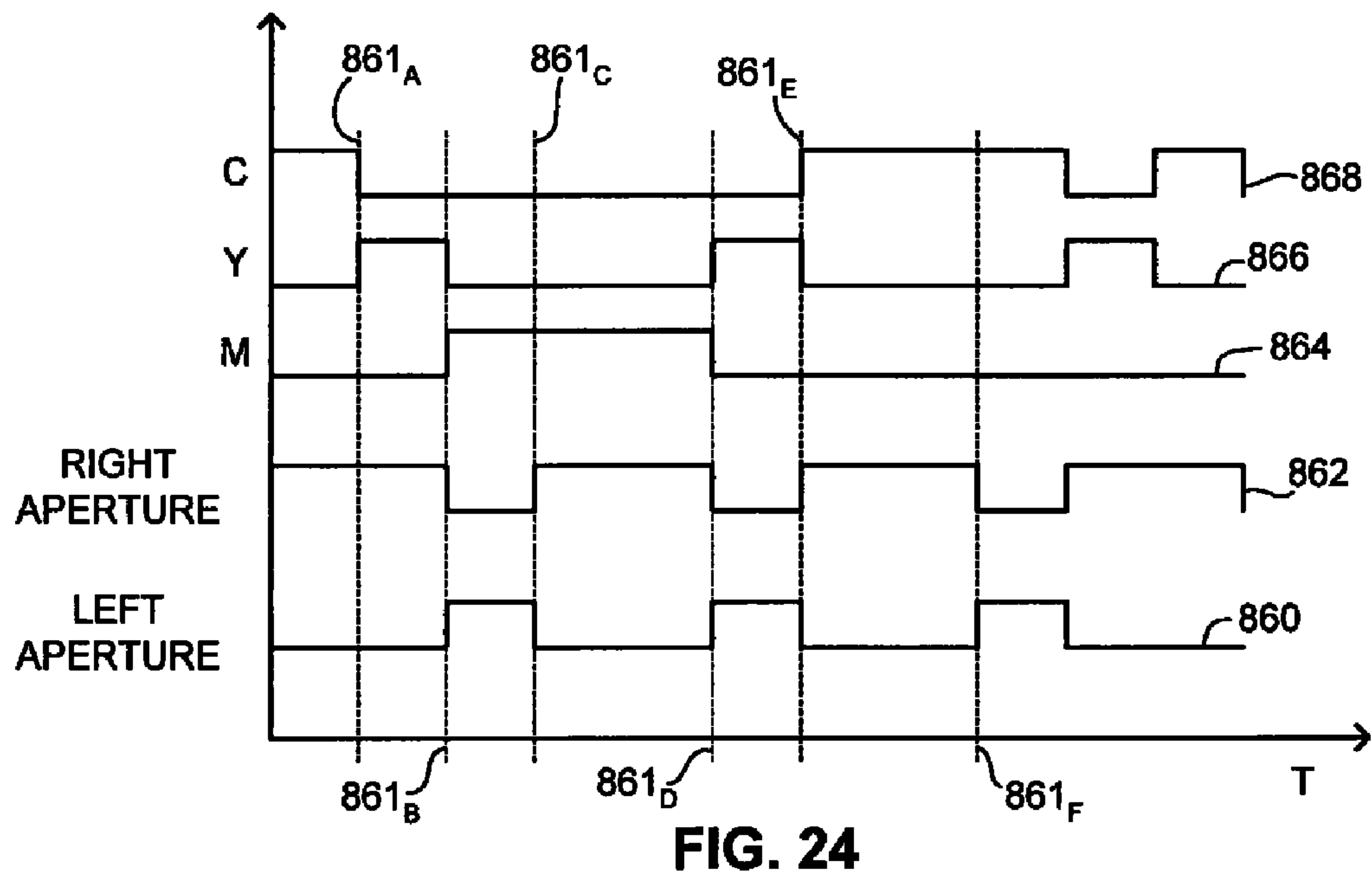


FIG. 24

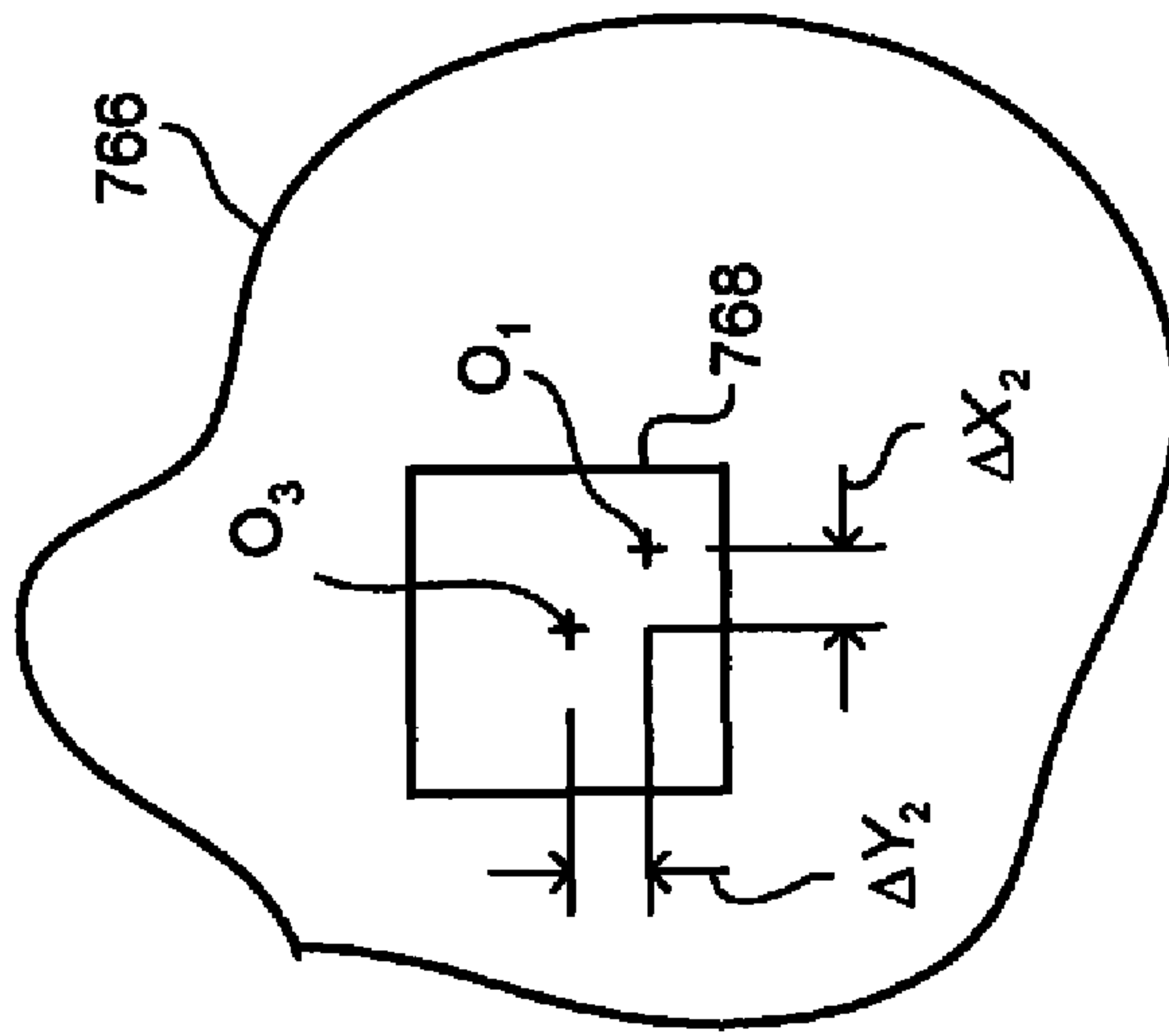


FIG. 25A

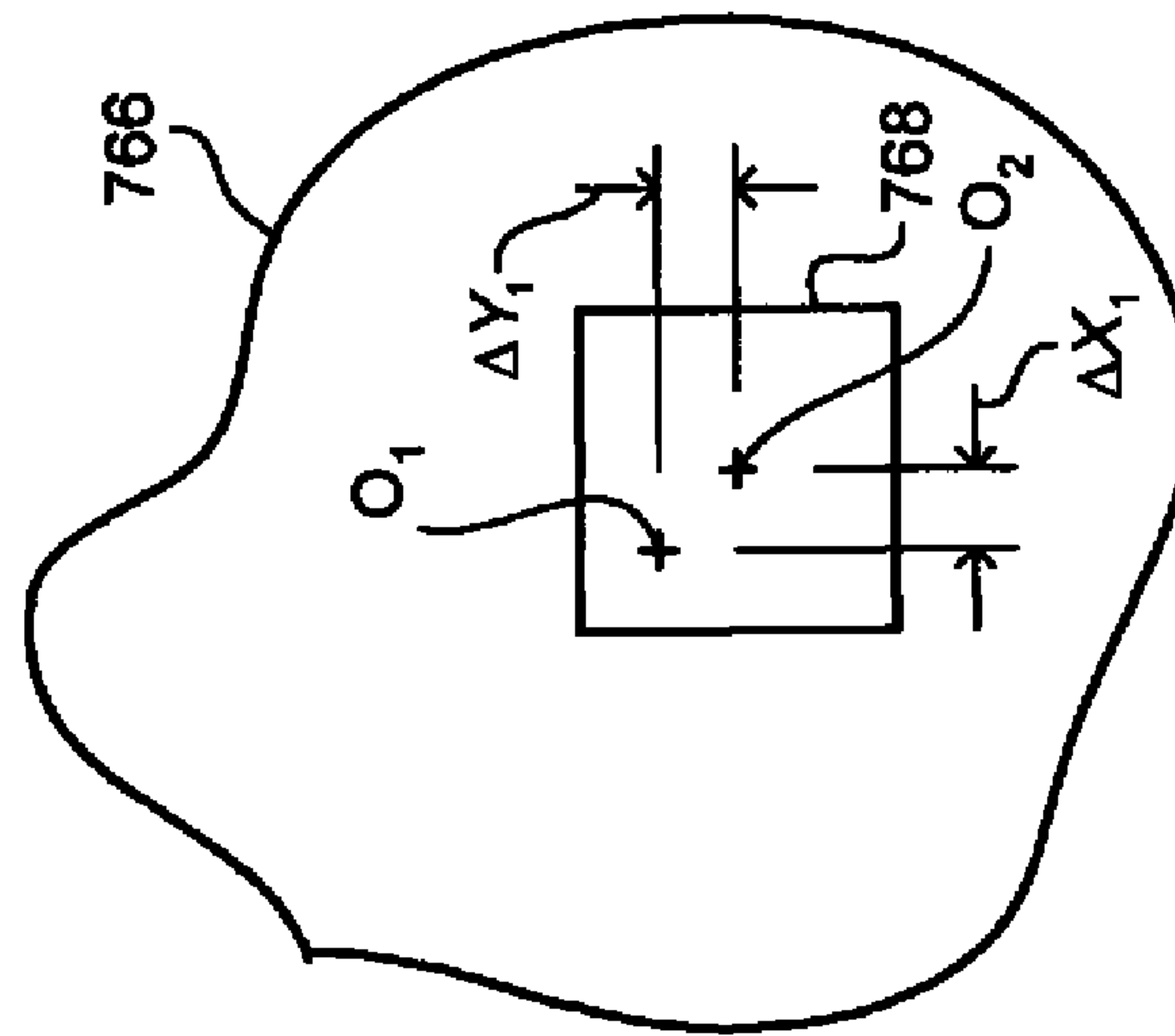


FIG. 25B

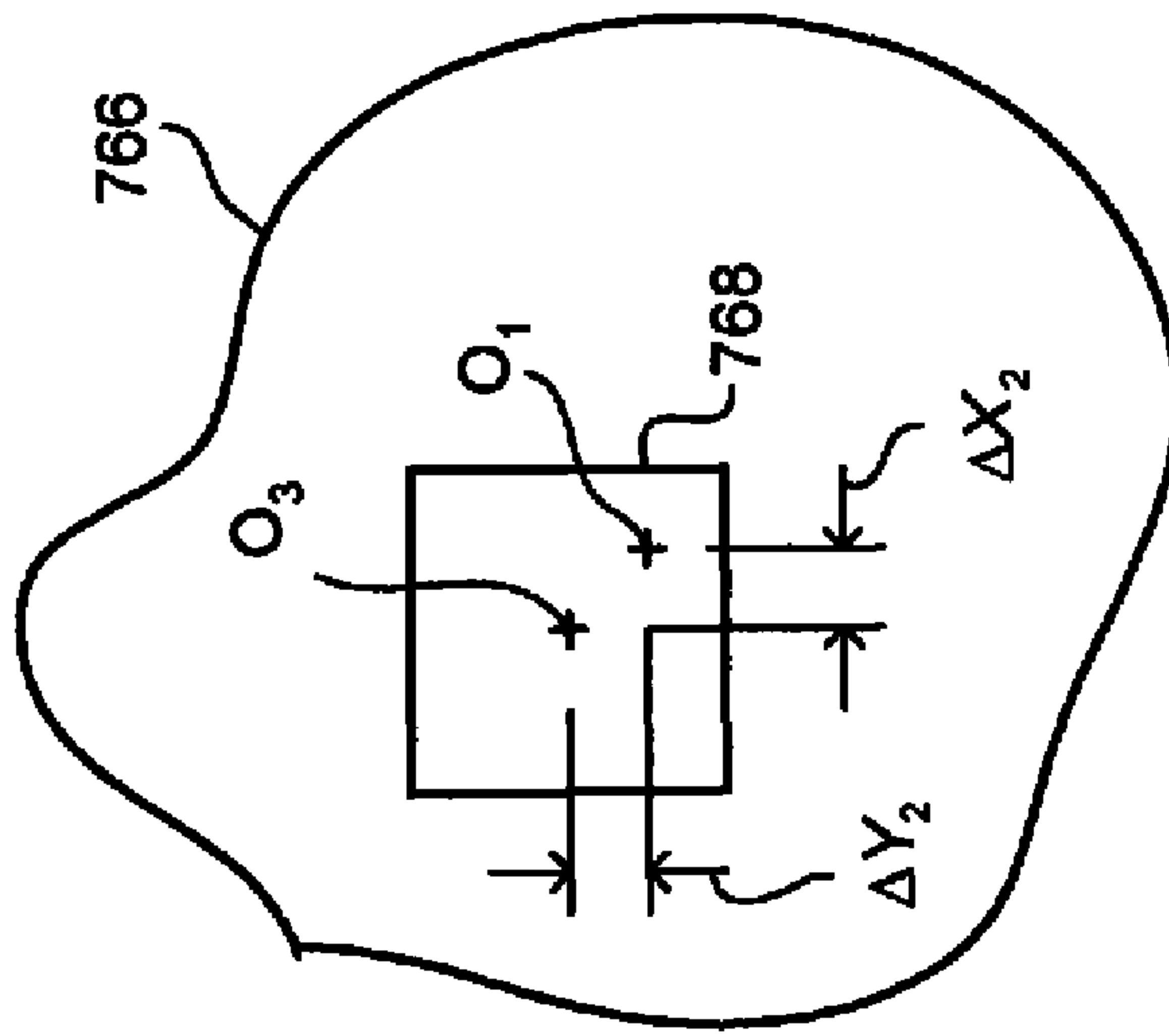


FIG. 25C

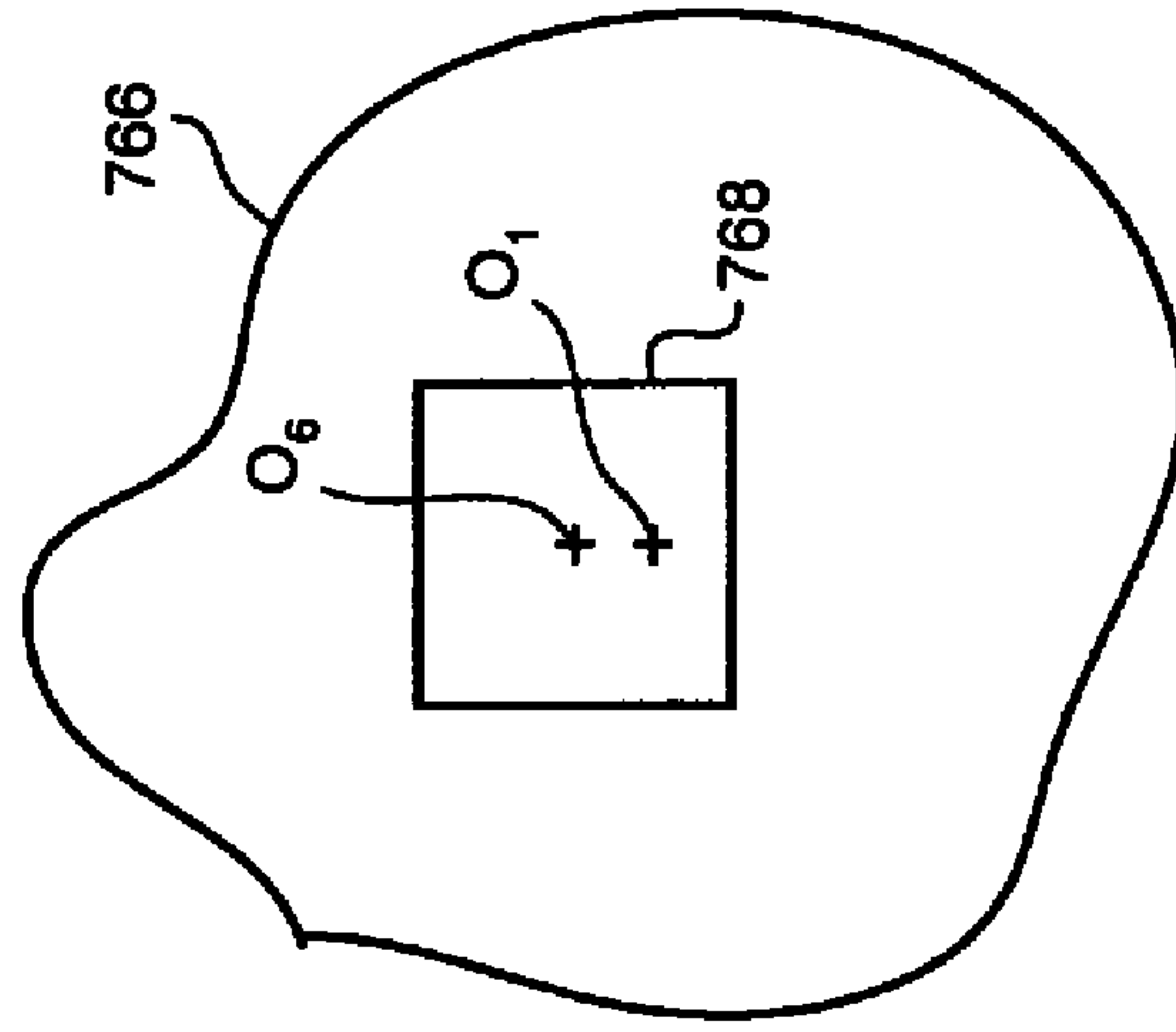


FIG. 25D

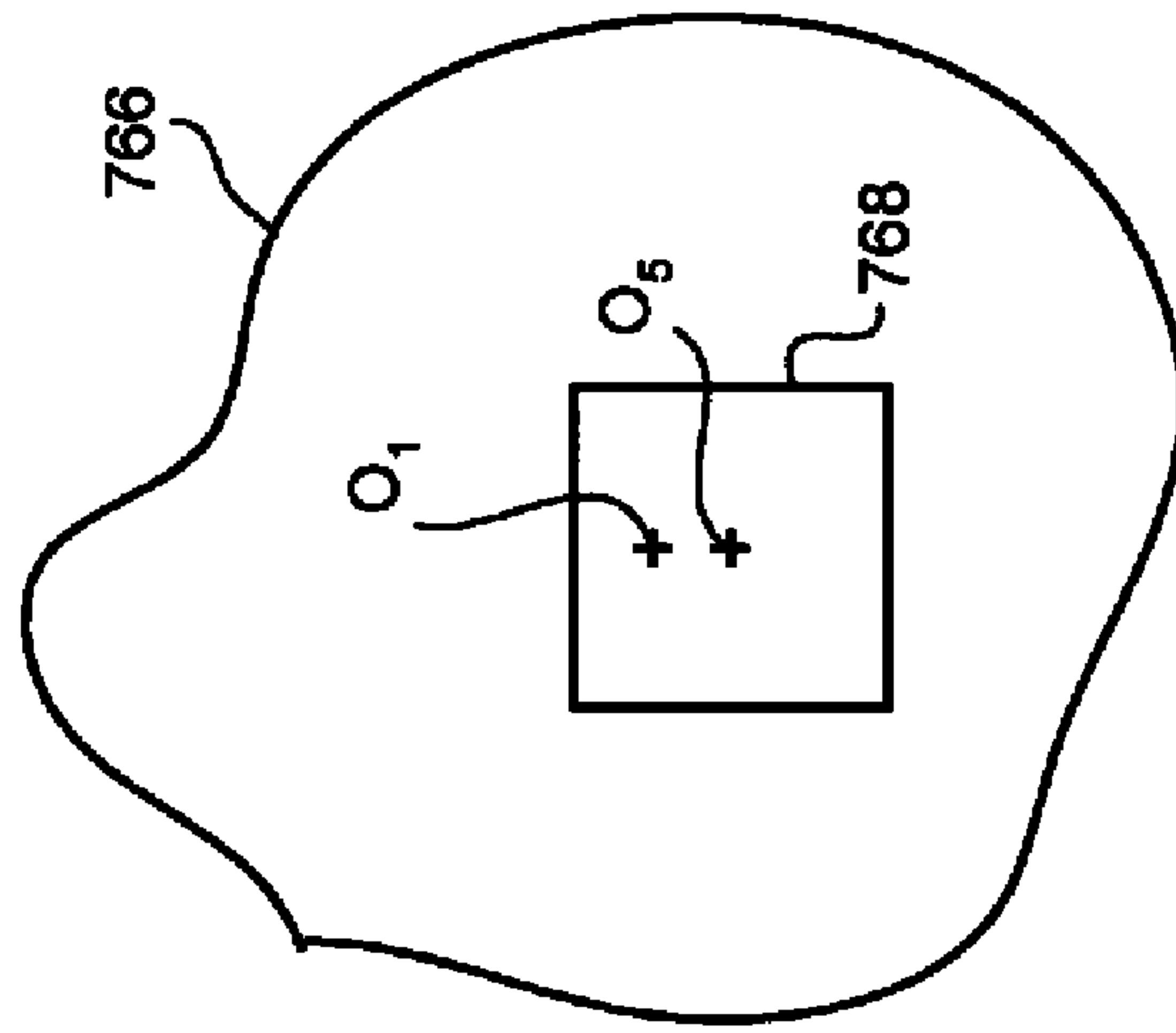


FIG. 25E

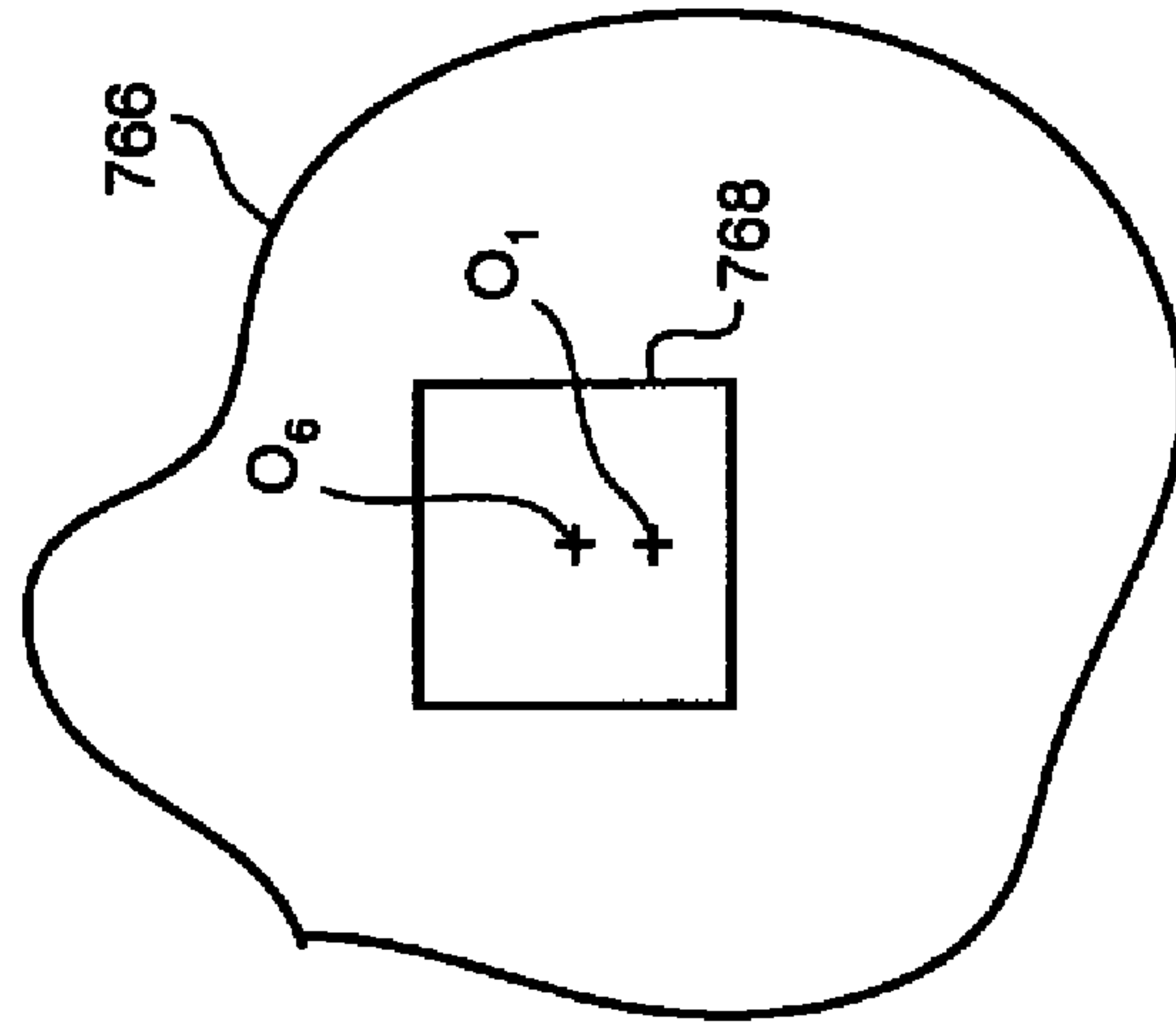


FIG. 25F

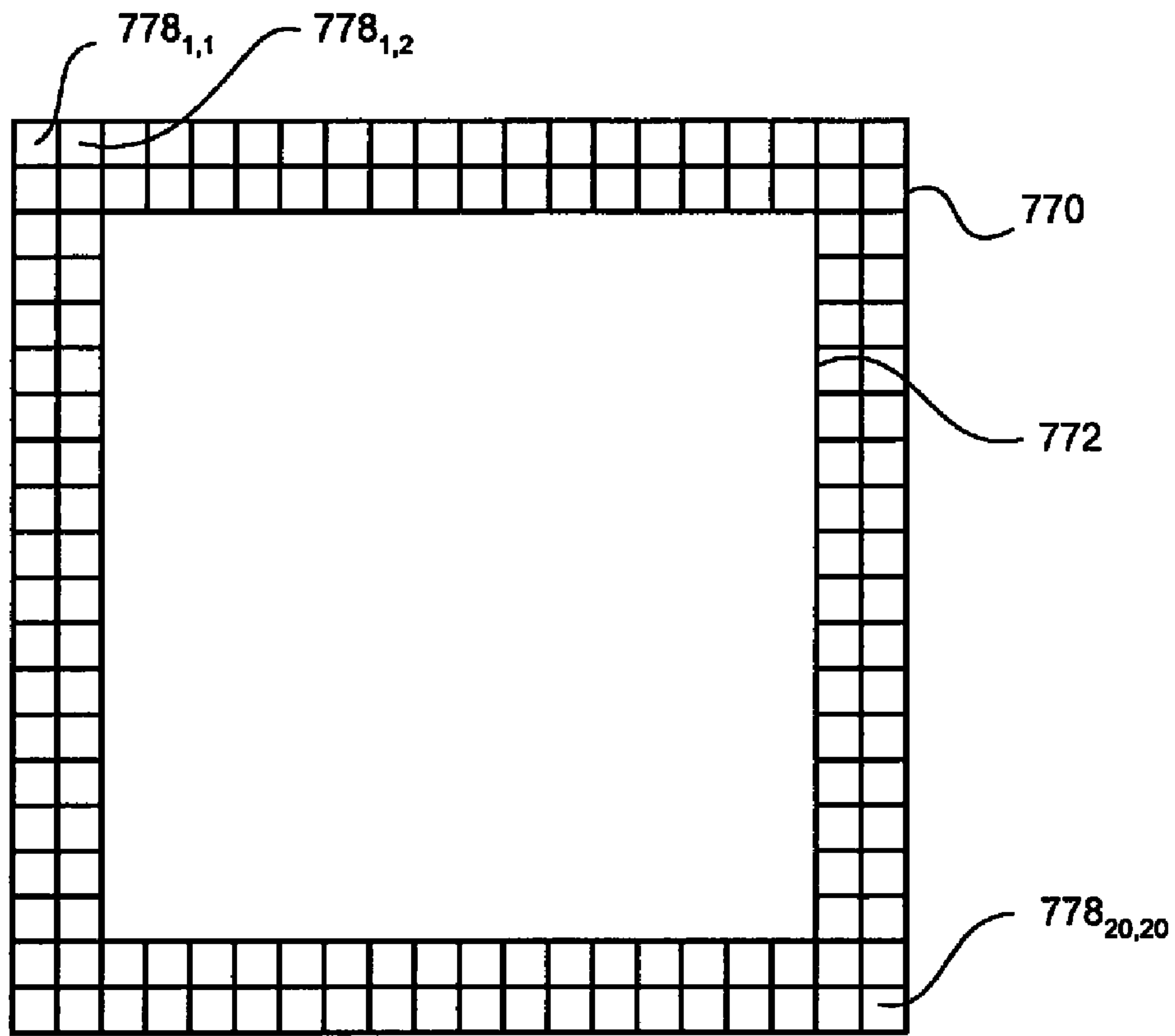


FIG. 26A

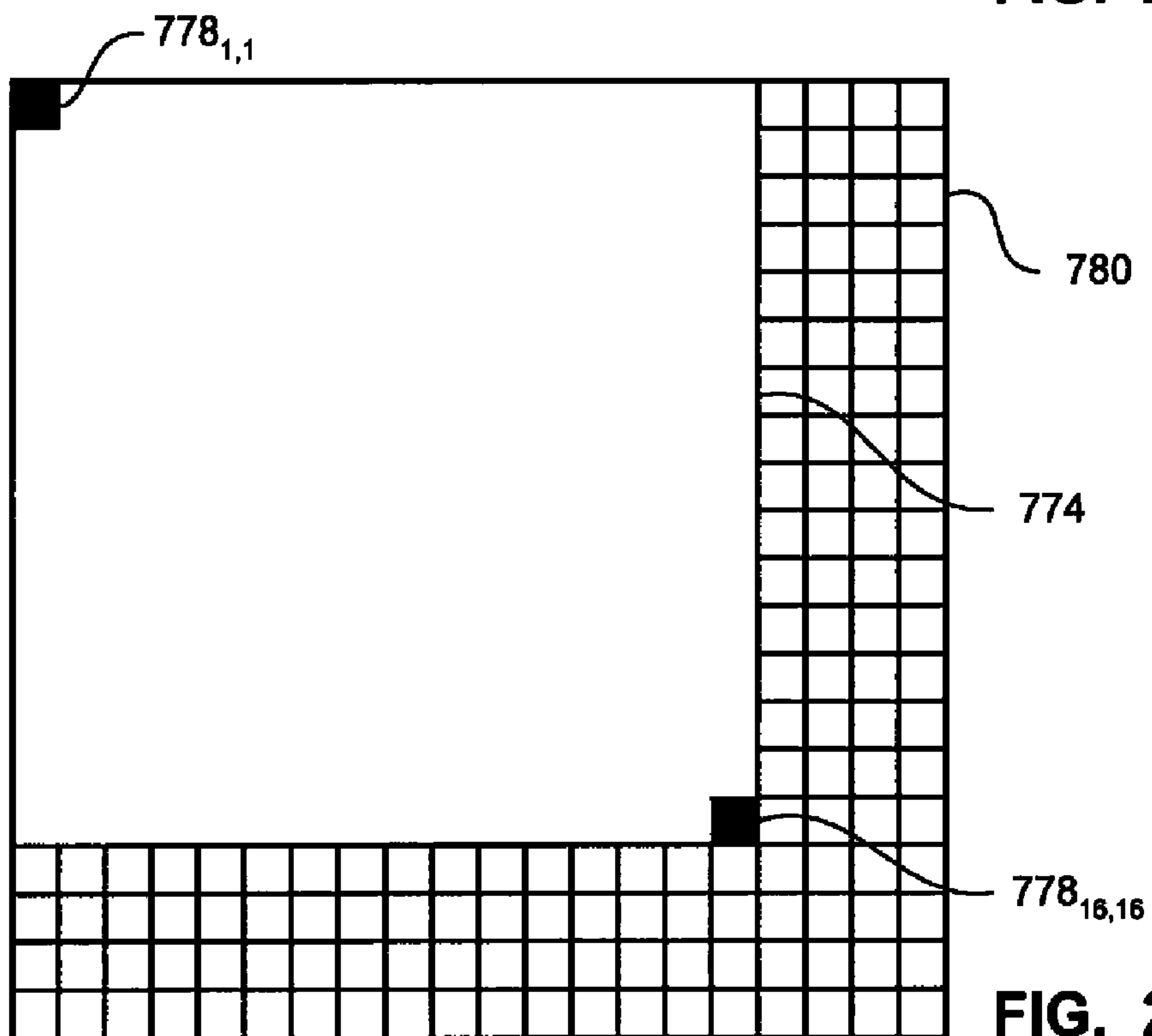


FIG. 26B

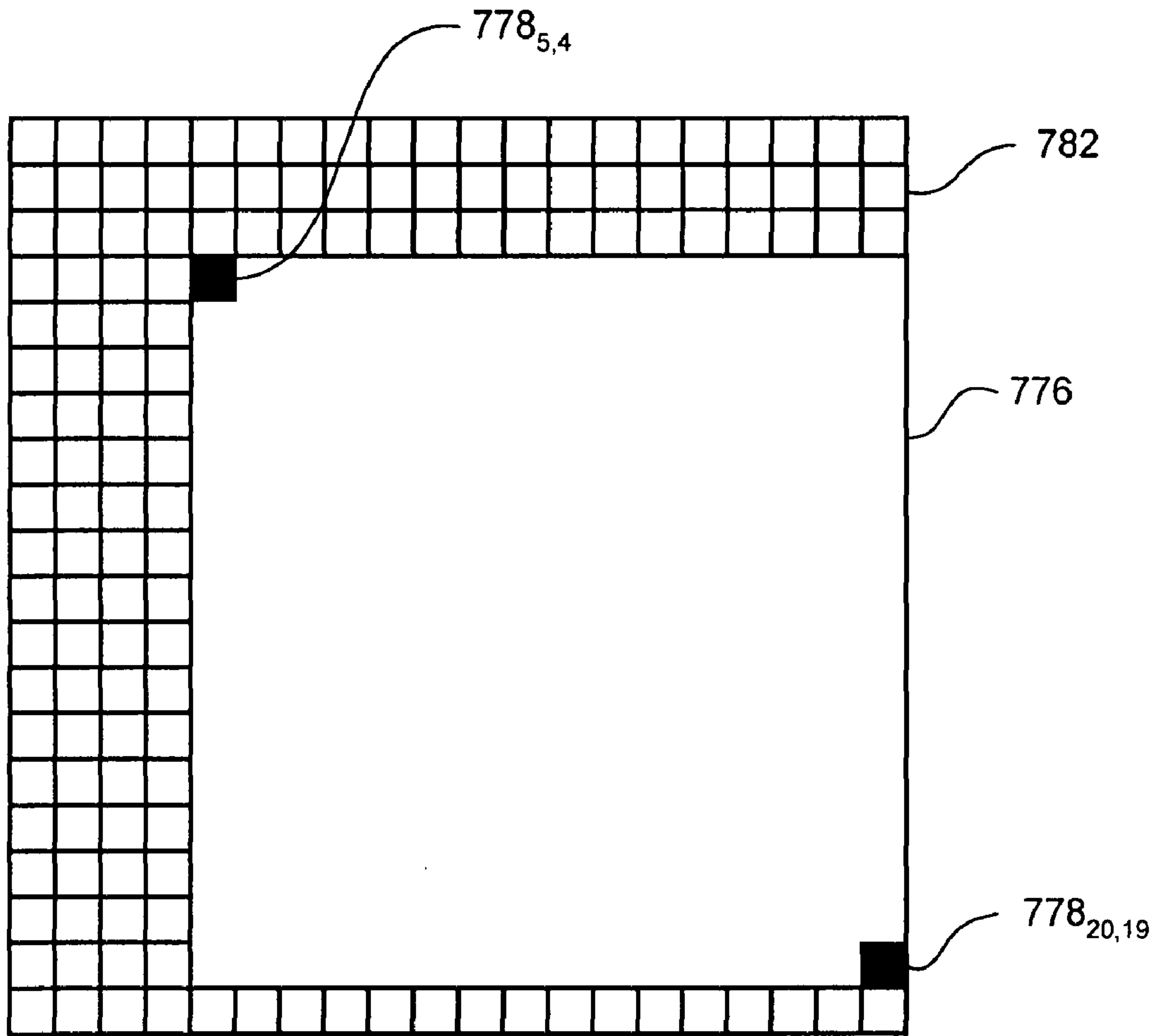
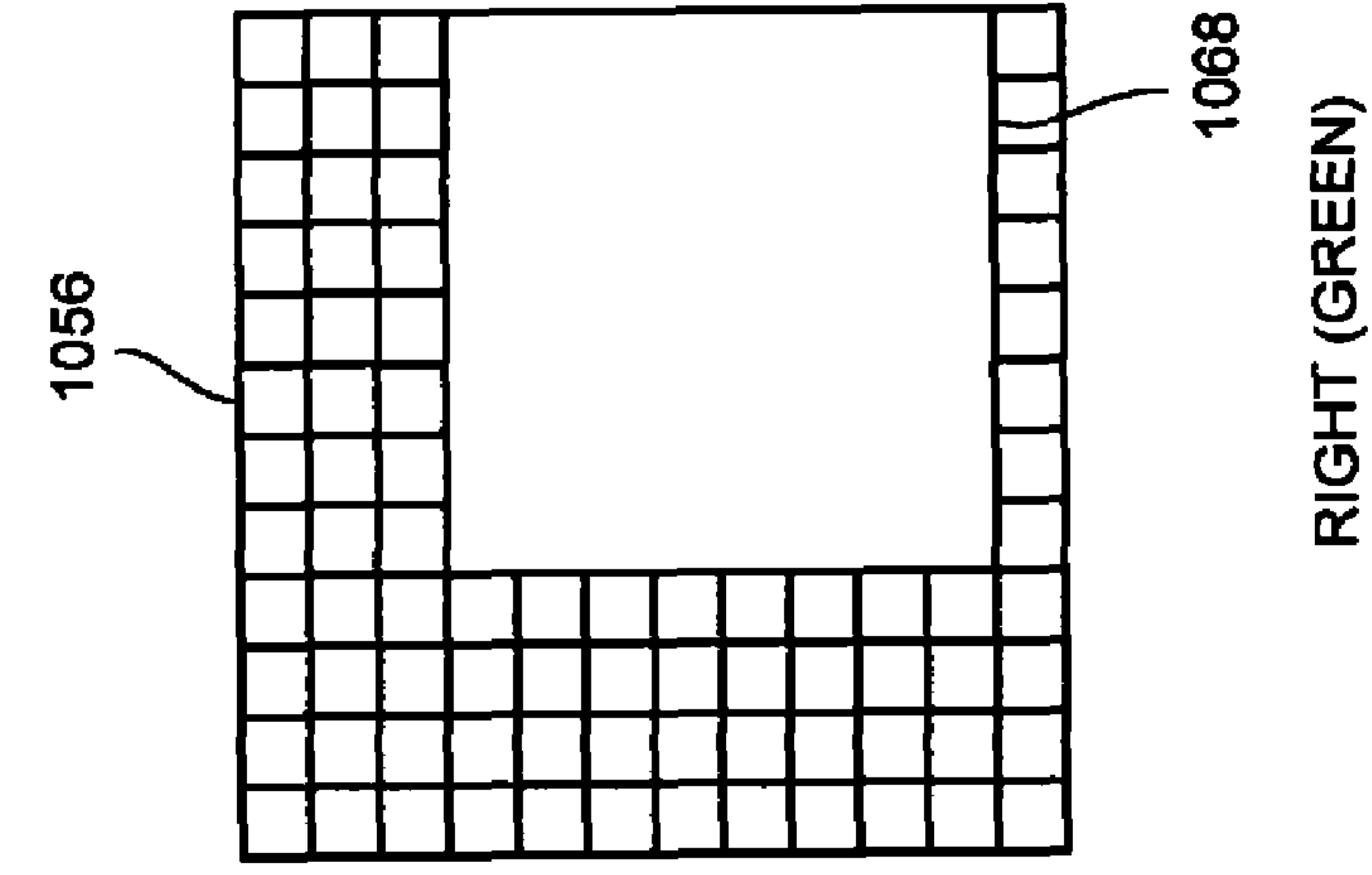
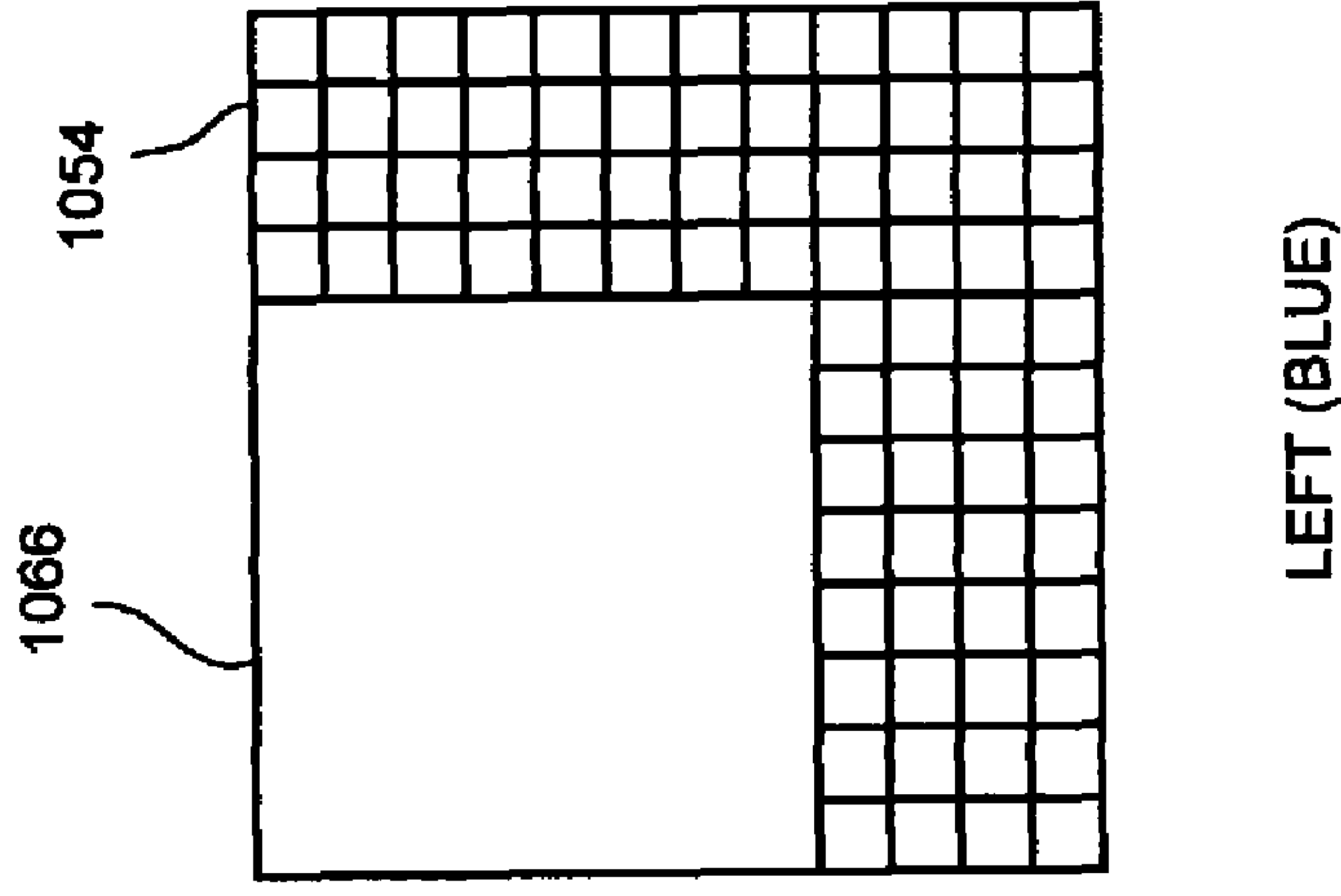


FIG. 26C



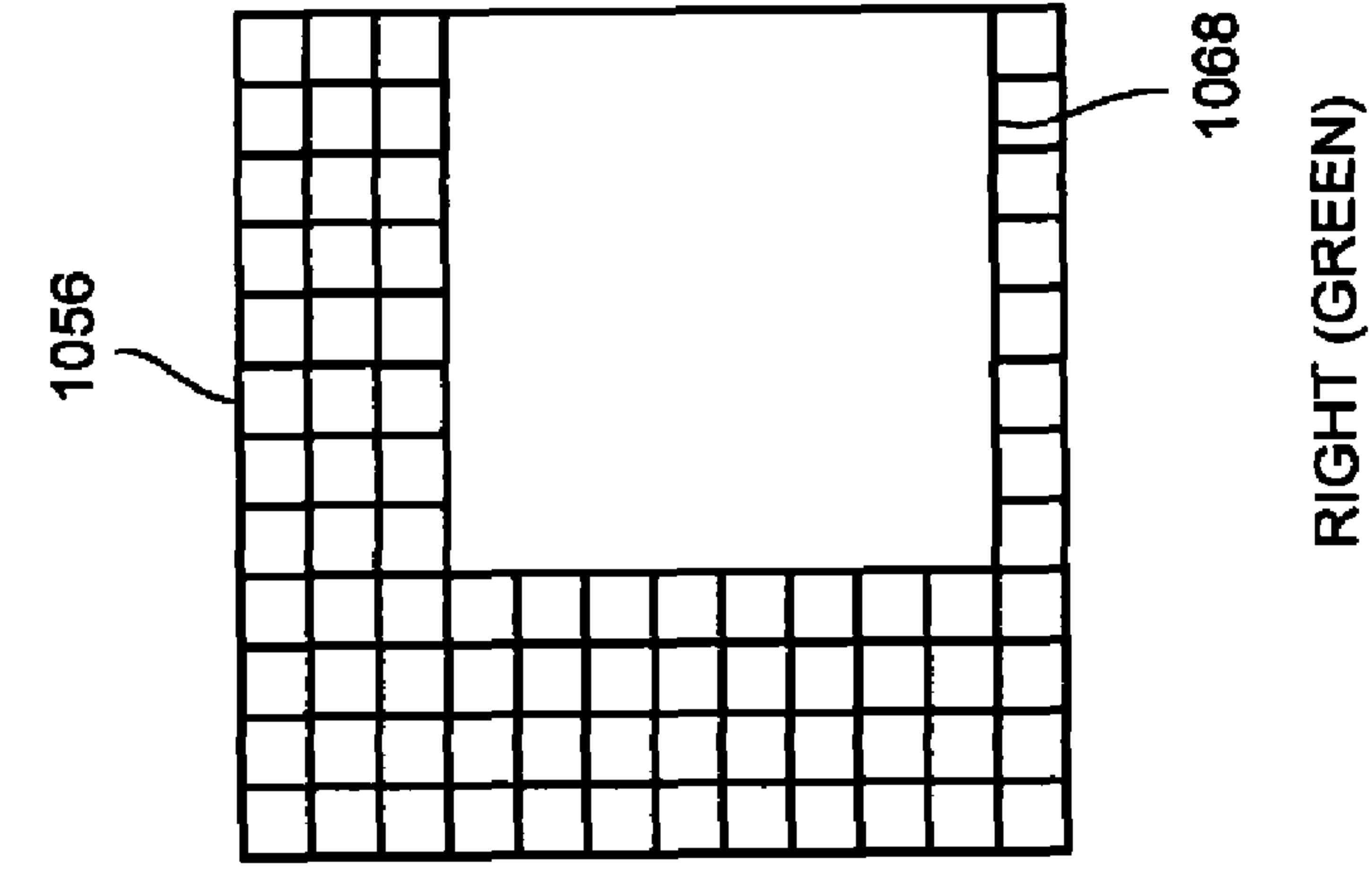
RIGHT (BLUE)

FIG. 27A



LEFT (BLUE)

FIG. 27B



RIGHT (GREEN)

FIG. 27C

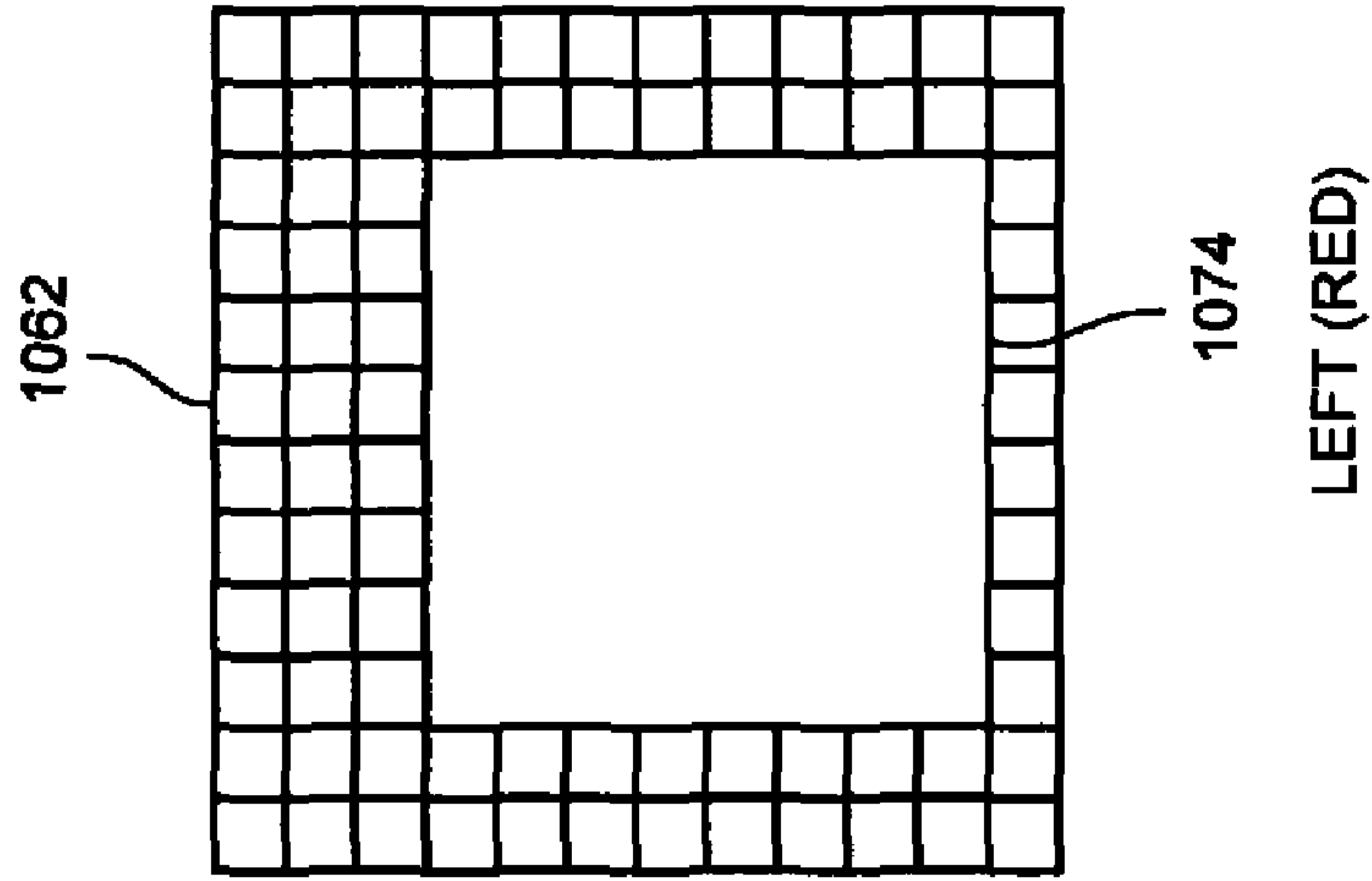


FIG. 27D

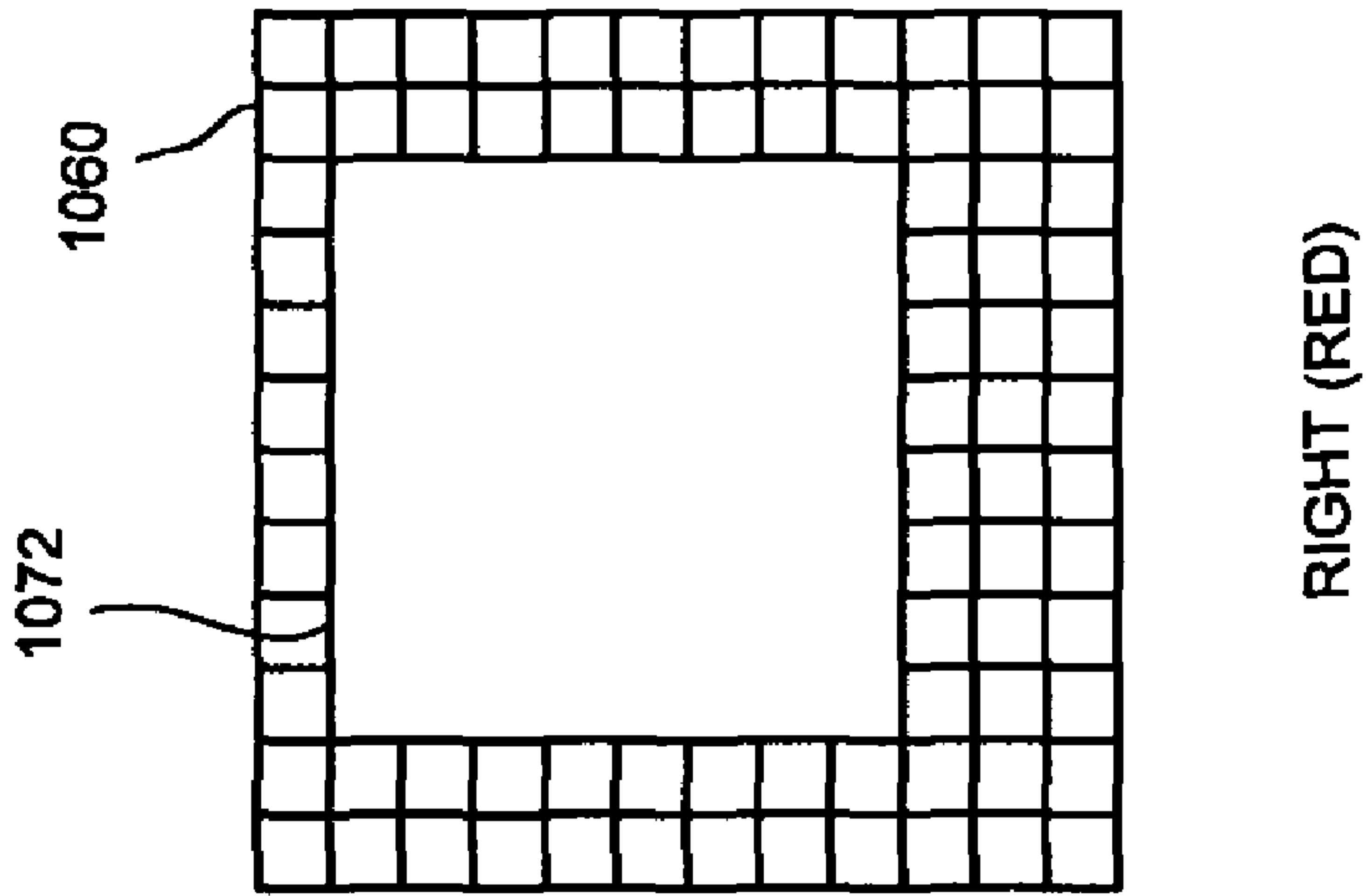


FIG. 27E

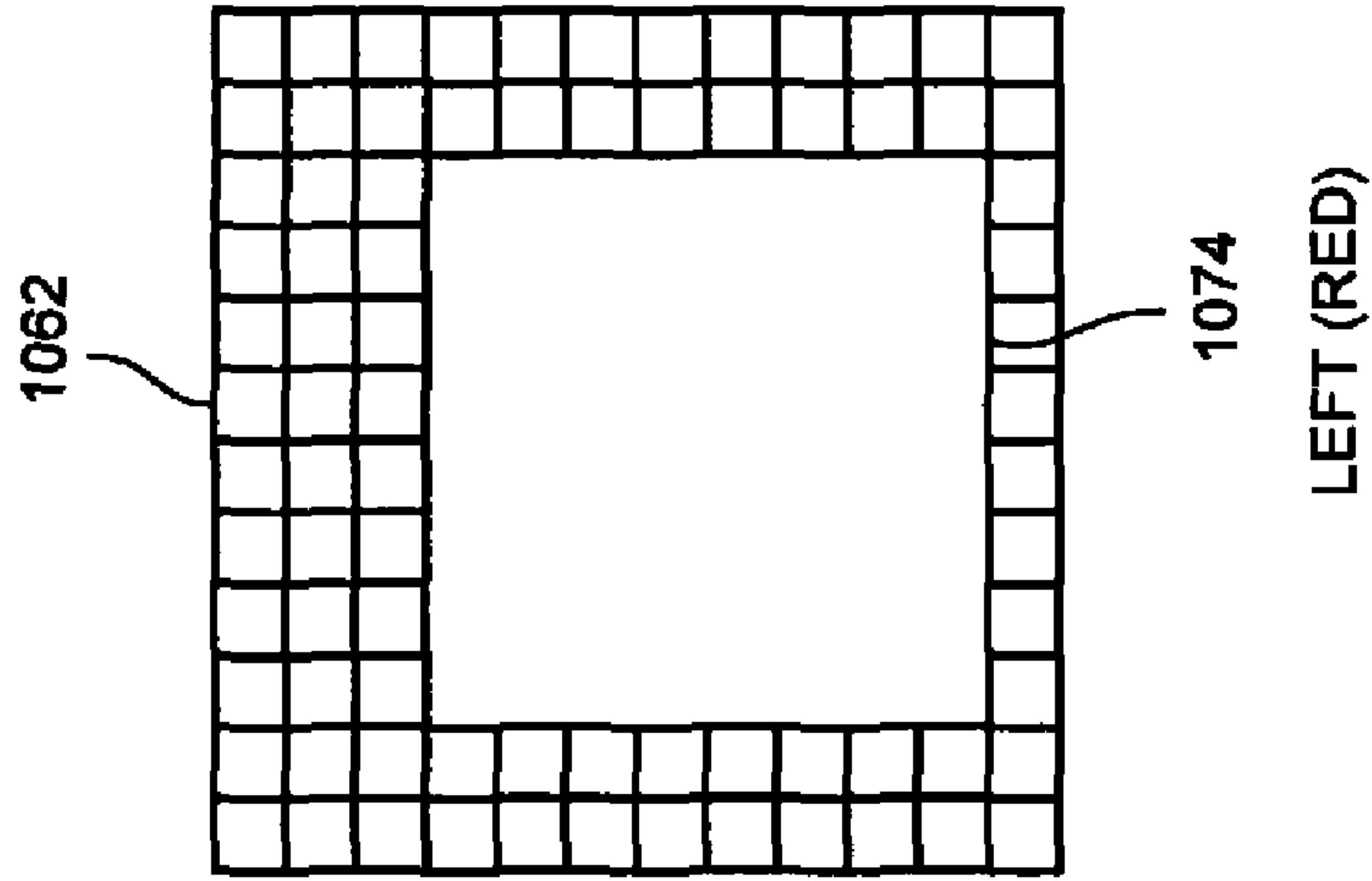


FIG. 27F

OPTICAL DEVICE

CROSS REFERENCE INFORMATION

This application is a Continuation-in-Part of application Ser. No. 09/257,850, filed Feb. 25, 1999 now U.S. Pat. No. 6,396,873 and 09/699,624 filed Oct. 30, 2000 now U.S. Pat. No. 7,154,527.

FIELD OF THE INVENTION

The present invention relates to endoscopes, microscopes and boroscopes, in general and to stereoscopic image pick up devices with color imaging capability, in particular.

BACKGROUND OF THE INVENTION

Stereoscopic image detection devices are known in the art. Such devices are required to obtain and provide a combination of small cross section and high image quality. It will be appreciated by those skilled in the art that high image quality, in general, is characterized by stereoscopic vision accuracy, color capabilities, high resolution and illumination requirements.

It is noted that conventional methods, which provide stereoscopic images, require a wider optical path than a monocular one. Such a widened optical path enlarges the cross-section required for the detection device considerably. Hence, the requirement for a small cross section is not maintained.

U.S. Pat. No. 5,527,263 to Zobel et al., is directed to a dual optical path stereo endoscope with simple optical adjustment. U.S. Pat. No. 5,776,049 to Takahashi, is directed to a "Stereo Endoscope Imaging Apparatus" and provides a device which utilizes a combination of two optical paths with two CCD units, capable of variable zoom.

Auto-stereoscopic devices, which utilize one optical system to provide a stereo effect, are also known in the art. Such a device is provided in U.S. Pat. No. 5,603,687 to Hori et al., which is directed to a device with two parallel optical axis and two CCD elements. Hori selected an asymmetrical approach, wherein one optical channel has a large aperture for light and details and the other optical channel provides a parallax image for stereoscopic imagery to the proximal CCD.

U.S. Pat. No. 5,613,936 to Czarnek et al., is directed to a stereoscopic endoscope device which utilizes light polarization and time multiplexing in order to transmit each different polarized image corresponding to left and right images multiplexed in time, through one optical channel that transfers images from the lateral side of the endoscope shaft. This endoscope has to be inserted deeper into the human cavity to receive a stereo image. It must also be used with a head mounted display device called "switched shutter glasses" that causes eye irritation. It is noted that according to Czarnek each image is received in 25% of original quality. As much as 50% of the light received from the object, is lost due to polarization considerations and as much as 50% of the remaining information is lost due to channel switching.

U.S. Pat. No. 5,588,948, to Takahashi et al., is directed to a Stereoscopic Endoscope. The stereo effect is produced by having a dividing pupil shutter, which splits the optical path onto the left and right sides, and the up and down sides. These sides are alternatively projected on a proximal image pickup device, using time multiplexing. According to another aspect of this reference includes a distal CCD, which is divided to left and right sides with a shading member separating them, for achieving space multiplexing.

U.S. Pat. No. 5,743,847 to Nakamura et al., is directed to a "Stereoscopic Endoscope Having Image Transmitting Optical-System and Pupil Dividing Unit that are Axially Movable With Respect to Each Other", which uses a plural pupil dividing means and one optical channel. U.S. Pat. No. 5,751,341 to Chaleki et al., is directed to a "Stereoscopic Endoscope System", which is basically a two channel endoscope, with one or two proximal image sensors. A rigid sheath with an angled distal tip could be attached to its edge and be rotated, for full view.

U.S. Pat. No. 5,800,341 to McKenna et al, who is directed to an "Electronically Steerable Endoscope", which provides different fields of view, without having to move the endoscope, using a plurality of CCD cells and processing means. U.S. Pat. No. 5,825,534 to Strahle, is directed to a "Stereo Endoscope having a Folded Sight Line" including stereo-endoscope optical channel, having a sight line folded relative to tube axis.

U.S. Pat. No. 5,828,487 to Greening et al., is directed to a "Stereoscopic Viewing System Using a Two Dimensional Lens System" which in general, provides an alternative R-L switching system. This system uses a laterally moving opaque leaf, between the endoscope and the camera, thus using one imaging system. U.S. Pat. No. 5,594,497 to Ahern, describes a distal color CCD, for monocular view in an elongated tube.

The above descriptions provide examples of auto-stereoscopic inventions, using different switching techniques (Time division multiplexing) and polarization of channels or pupil divisions (spatial multiplexing), all in an elongated shaft. When color image pick up devices are used within these systems, the system suffers from reduced resolution, loss of time related information or a widened cross section.

The issue of color imagery or the issue of a shaft-less endoscope is not embedded into any solution. To offer higher flexibility and to reduce mechanical and optical constraints it is desired to advance the image pick-up device to the frontal part of the endoscope. This allows much higher articulation and lends itself easily to a flexible endoscope. Having a frontal pick up device compromises the resolution of the color device due to size constraints (at this time).

U.S. Pat. No. 5,076,687 to Adelson, is directed to an "Optical Ranging Apparatus" which is, in general a depth measuring device utilizing a lenticular lens and a cluster of pixels.

U.S. Pat. No. 5,760,827 to Faris, is directed to "Pixel Data Processing System and Method for Producing Spectrally-Multiplexed Images of Three-Dimensional Imagery for Use in Stereoscopic Viewing Thereof" and demonstrates the use of multiplexing in color and as such, offers a solution for having a color stereo imagery with one sensor. Nevertheless, such a system requires several sequential passes to be acquired from the object, for creating a stereo color image.

U.S. Pat. No. 5,812,187 to Watanabe, is directed to an Electronic Endoscope Apparatus. This device provides a multi-color image using a monochromatic detector and a mechanical multi-wavelength-illuminating device. The monochromatic detector detects an image, each time the multi-wavelength-illuminating device produces light at a different wavelength.

SUMMARY OF THE PRESENT INVENTION

It is an object of the present invention to provide a novel system for stereoscopic imaging using a lenticular lens layer and a sensor array, and a novel method for operating the same, which overcomes the disadvantages of the prior art.

In accordance with the present invention, there is thus provided a stereoscopic device, which includes a lenticular lens layer and a color light sensor array. The lenticular lens layer includes a plurality of lenticular elements. Each of the lenticular elements is located in front of a selected group of the light sensors of the sensor array, thereby directing light from different directions to different light sensors within the selected group of the light sensors.

In accordance with a further aspect of the invention, there is provided a stereoscopic device, which includes a lenticular lens layer and a light sensor array, including a plurality of light sensors, where each of the light sensors detects light at a predetermined range of wavelengths.

The stereoscopic device according to the invention can be constructed as a large-scale device, such as a television camera or a small-scale device such as an endoscope.

In a stereoscopic device according to the invention, each of the lenticular elements includes light directing means, which distinguish between at least two directions of light. For example, each of the lenticular elements can be shaped in a general semi-cylindrical shape. Each of the lenticular elements can alternatively include light directing means, which distinguish between four directions of light. For example, such a lenticular element can be shaped in a general semi-spherical shape.

According to one aspect of the invention, each of the selected groups of the light sensors includes an even number of light sensors. According to another aspect of the invention, each of the selected groups of the light sensors includes an odd number of light sensors.

The stereoscopic device of the invention can further include an illuminating unit. This light illuminating unit can surround the lenticular lens layer. An illumination unit according to the invention includes a light source, a light distribution unit and light guiding means connected between the light source and the light dispersing unit. The light guiding means guides light from the light source to the light dispersing unit. According to one aspect of the invention, the light dispersing unit surrounds the lenticular lens layer.

The light illuminating unit can produce light in a predetermined range of wavelengths. According to another aspect of the invention, the light illuminating unit produces at least two alternating beams of light, where each of the beams of light is characterized as being in a different range of wavelengths.

The stereoscopic device according to the invention, can further include a controller connected to the array of light sensors. This controller produces an image for each of the different directions, by combining data received from the light sensors respective of each of the different directions.

This controller can be connected to the array of light sensors. Accordingly, the controller produces an image for each combination of a selected one of the different directions and a selected one of the beams of light, by combining data received from the light sensors respective of each of the different directions, with respect to the currently illuminating one of the beams of light.

The stereoscopic device according to the invention can further include capturing means, connected to the array of light sensors, for capturing data received from light sensors and a storage unit for storing the captured data. The stereoscopic device can further include a stereoscopic display unit, connected to the controller, for producing the image in a stereoscopic manner. The produced image can be partially stereoscopic.

The predetermined ranges of wavelengths, which are applicable for the light sensors as well as for the illumination light beams can be substantially visible red color light, sub-

stantially visible green color light, substantially visible blue color light, substantially visible cyan color light, substantially visible yellow color light, substantially visible magenta color light, substantially infra-red light, substantially ultra-violet light, visible light, and the like.

For example, either the light sensor array or the light beams can include a color combination of red-green-blue (RGB), cyan-yellow-magenta-green (CYMG), a white light color combination, and the like.

In accordance with a further aspect of the invention, there is thus provided a method for detecting a stereoscopic image. The method includes the steps of splitting light which arrives from different directions, using a lenticular lens layer, thereby producing at least two images, which are intertwined in a master image, and detecting the master image.

The method can further include the step of reconstructing each of the images from the master image. In addition, the method can further include the step of displaying the images using a stereoscopic display device.

Furthermore, the method can include the step of simultaneously displaying the images on a stereoscopic display device. In addition, the method can further include the steps of sequentially illuminating a detected area with alternating beams of light of different ranges of wavelength, and associating the master image in time, with the currently illuminating ranges of wavelength.

The step of reconstructing can include the steps of determining a range of wavelengths for each pixel within each one of the images, and determining an intensity level for each pixel within each one of the images. The step of reconstructing can further include the steps of selecting one of the pixels, associated with a predetermined range of wavelengths and determining the pixels associated with another range of wavelengths, in the vicinity of the selected pixel. The step of reconstructing can further include the steps of calculating an approximated level of the other range of wavelengths at the location of the selected pixel and starting again from the step of selecting.

In accordance with another aspect of the present invention, there is thus provided a stereoscopic device for detecting a stereoscopic image. The stereoscopic device includes at least two apertures, a multi wavelength light sensor array and a controllable multi wavelength illumination unit. Each aperture includes a plurality of light valves. The controllable multi wavelength illumination unit produces at least two alternating beams of light, where each beam of light is characterized as being in a different range of wavelengths. Each light valve is operative to open at a different predetermined timing. Furthermore, the multi wavelength light sensor array detects a plurality of images, where each of the images corresponds to a predetermined combination of an open state of a selected light valve and a selected mode.

In accordance with a further aspect of the present invention, there is thus provided a method for detecting a stereoscopic image. The method includes the steps of alternating between at least two apertures, producing a sequence of at least two illumination beams and detecting a plurality of frames. The apertures are directed at an object. The illumination beams are produced in different ranges of wavelengths. Each of the frames is detected for a combination, which includes a selected aperture and a selected illumination beam.

In accordance with another aspect of the present invention, there is thus provided a stereoscopic device. The stereoscopic device includes a sensor assembly for detecting a sequence of stereoscopic images of an object, a movement detector for detecting the movements of the sensor assembly relative to the object, and a processing unit connected to the sensor

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assembly and to the movement detector. The processing unit selects portions of the stereoscopic images, according to a signal received from the movement detector, thereby producing a visually stable sequence of display images.

In accordance with a further aspect of the present invention, there is thus provided a method for producing a stable sequence of stereoscopic images of an object. The method includes the steps of detecting a plurality of stereoscopic images, for each of the stereoscopic images, detecting the movements of the stereoscopic sensor assembly relative to the object, and for each the stereoscopic images, selecting a portion of each of the stereoscopic images, according to the respective movement. The stereoscopic images are detected by employing a stereoscopic sensor assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description taken in conjunction with the drawings in which:

FIG. 1 is a schematic illustration of a three dimensional object and a stereoscopic vision apparatus, constructed and operative in accordance with a preferred embodiment of the present invention;

FIG. 2 is a schematic illustration of a stereoscopic vision apparatus, constructed and operative in accordance with another preferred embodiment of the present invention;

FIG. 3A is a schematic illustration of a super-pixel, constructed and operative in accordance with a further preferred embodiment of the present invention;

FIG. 3B is a schematic illustration of the super-pixel of FIG. 3A and a lenticular element, constructed and operative in accordance with a another preferred embodiment of the present invention;

FIG. 3C is a schematic illustration of a sensor array and a lenticular lens layer, constructed and operative in accordance with a further preferred embodiment of the present invention;

FIG. 4 is a schematic illustration of a super-pixel, constructed and operative in accordance with another preferred embodiment of the present invention;

FIG. 5A is a schematic illustration of a color super-pixel, constructed and operative in accordance with a further preferred embodiment of the present invention;

FIG. 5B is a schematic illustration of the color super-pixel of FIG. 5A, with a single lenticular element, constructed and operative in accordance with another preferred embodiment of the present invention;

FIG. 5C is a schematic illustration of the color super-pixel of FIG. 5A, combined with three lenticular elements, constructed and operative in accordance with a further preferred embodiment of the present invention;

FIG. 6 is a schematic illustration of a sensor array and a lenticular lens layer, constructed and operative in accordance with another preferred embodiment of the present invention;

FIG. 7A is a schematic illustration of a method for operating the apparatus of FIG. 2, operative in accordance with a further preferred embodiment of the present invention;

FIG. 7B is an illustration in detail of a step of the method of FIG. 7A;

FIG. 7C is a schematic illustration of a sensor array and a lenticular lens layer, constructed and operative in accordance with another preferred embodiment of the present invention;

FIG. 8 is a schematic illustration of a stereoscopic vision apparatus, constructed and operative in accordance with a further preferred embodiment of the present invention;

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FIG. 9A is a view in perspective of a section of light sensors, and a lenticular element, constructed and operative in accordance with another preferred embodiment of the present invention;

FIG. 9B is a view from the bottom of the lenticular element and the section of light sensors of FIG. 9A;

FIG. 9C is a view from the side of the lenticular element and the section of light sensors of FIG. 9A;

FIG. 10 is a view in perspective of a section of light sensors, and a lenticular element, constructed and operative in accordance with a further preferred embodiment of the present invention;

FIG. 11 is a view in perspective of a sensor array and a lenticular lens layer, constructed and operative in accordance with another preferred embodiment of the present invention;

FIG. 12A is a schematic illustration of a detection apparatus, constructed and operative in accordance with a further preferred embodiment of the present invention;

FIG. 12B is another schematic illustration of the detection apparatus of FIG. 12A;

FIG. 13 is a schematic illustration of a detection apparatus, constructed and operative in accordance with another preferred embodiment of the present invention;

FIG. 14A is a partially schematic partially perspective illustration of a combined illumination and detection device, constructed and operative in accordance with a further preferred embodiment of the present invention;

FIG. 14B is a partially schematic partially perspective illustration of the combined illumination and detection device of FIG. 14A, a controller and output frames, constructed and operative in accordance with another preferred embodiment of the present invention;

FIG. 15 is an illustration in perspective of a color illumination unit, constructed and operative in accordance with a further preferred embodiment of the present invention;

FIG. 16 is a view in perspective of a sensor array and a partial lenticular lens layer, constructed and operative in accordance with another preferred embodiment of the present invention;

FIG. 17 is a view in perspective of a sensor array and a partial lenticular lens layer, constructed and operative in accordance with a further preferred embodiment of the present invention;

FIG. 18 is a schematic illustration of a sensor array and a partial lenticular lens layer, constructed and operative in accordance with another preferred embodiment of the present invention;

FIG. 19 is a schematic illustration of a sensor array and a partial lenticular lens layer, constructed and operative in accordance with a further preferred embodiment of the present invention;

FIG. 20A is a schematic illustration of a system, for producing a color stereoscopic image, in a right side detection mode, constructed and operative in accordance with another preferred embodiment of the invention;

FIG. 20B is an illustration of the system of FIG. 20A, in a left-side detection mode;

FIG. 21A is a schematic illustration of a timing sequence, in which the controller of the system of FIG. 20A synchronizes the operation of illumination unit, apertures and image detector of that same system;

FIG. 21B is a schematic illustration of another timing sequence, in which the controller of FIG. 20A synchronizes the operation of the illumination unit, right and left apertures and the image detector;

FIG. 22 is a schematic illustration of a method for operating the system of FIGS. 20A and 20B, operative in accordance with a further preferred embodiment of the present invention;

FIG. 23 is a schematic illustration of a timing scheme, for operating the system of FIGS. 20A and 20B, in accordance with another preferred embodiment of the present invention;

FIG. 24 is a schematic illustration of a timing scheme, for operating the system of FIGS. 20A and 20B, in accordance with a further preferred embodiment of the present invention;

FIG. 25A is a schematic illustration of an object and a sensor assembly, when the sensor assembly is located at an initial position with respect to the object;

FIG. 25B is a schematic illustration of the object and the sensor assembly of FIG. 25A, when the sensor assembly has moved to a new position;

FIG. 25C is a schematic illustration of the object and the sensor assembly of FIG. 25A, when the sensor assembly has moved to another position;

FIG. 25D is a schematic illustration of the object and the sensor assembly of FIG. 25A, when the sensor assembly has moved to a further new position;

FIG. 25E is a schematic illustration of the object and the sensor assembly of FIG. 25A, when the sensor assembly has moved to another new position;

FIG. 25F is a schematic illustration of the object and the sensor assembly of FIG. 25A, when the sensor assembly has moved to a further new position;

FIG. 26A is a schematic illustration of a detected image, as detected by sensor assembly of FIG. 25A, and a respective displayed image, in accordance with a further preferred embodiment of the present invention;

FIG. 26B is a schematic illustration of a detected image, as detected by sensor assembly of FIG. 25B, and a respective displayed image;

FIG. 26C is a schematic illustration of a detected image, as detected by the sensor assembly of FIG. 25C, and a respective displayed image;

FIG. 27A is a schematic illustration of a sub-matrix, in accordance with another preferred embodiment of the present invention, when the sensor assembly is at a location illustrated in FIG. 25A;

FIG. 27B is a schematic illustration of a sub-matrix, when the sensor assembly is at a location illustrated in FIG. 25B;

FIG. 27C is a schematic illustration of a sub-matrix, when the sensor assembly is at a location illustrated in FIG. 25C;

FIG. 27D is a schematic illustration of a sub-matrix, when the sensor assembly is at a location illustrated in FIG. 25D;

FIG. 27E is a schematic illustration of a sub-matrix, when the sensor assembly is at a location illustrated in FIG. 25E; and

FIG. 27F is a schematic illustration of a sub-matrix, when the sensor assembly is at a location illustrated in FIG. 25F.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention overcomes the disadvantages of the prior art by providing a continuous vision stereoscopic apparatus, using a generally lenticular lens layer, a light sensor array and an image processing system.

Reference is now made to FIG. 1, which is a schematic illustration of a three dimensional object and a stereoscopic vision apparatus, generally referenced 100, constructed and operative in accordance with a preferred embodiment of the present invention. Apparatus 100 includes a lenticular lens layer 104, a light sensor array 102, a processor 106 and two

display devices 108R and 108L. Apparatus 100 is placed in front of a three-dimensional object 150. An optical assembly 152 is placed between apparatus 100 and object 150, for focusing the image of object 150 on light sensor array 102.

Is Light sensor array 102 includes a plurality of sensors 110, 111, 112, 113, 114, 115, 116, 117, 118 and 119. Lenticular lens layer 104 includes a plurality of lenticular elements 130, 132, 134, 136 and 138. Each one of the lenticular elements is located above two light sensors, in a way that lenticular element 130 is located above sensors 110 and 111, lenticular element 132 is located above sensors 112 and 113, lenticular element 134 is located above sensors 114 and 115, lenticular element 136 is located above sensors 116 and 117 and lenticular element 138 is located above sensors 118 and 119.

The light sensors 110, 111, 112, 113, 114, 115, 116, 117, 118, and 119, detect light as directed by the lenticular lens elements 130, 132, 134, 136 and 138, and provide respective information to the processor 106. The processor 106 processes this information, produces a pair of images, as will be explained in detail herein below, and provides them to the display units 108R and 108L, which in turn produce visual representations of these images.

In general, each lenticular element directs light rays, which arrive from a predetermined direction to a predetermined location, and light rays which arrive from another predetermined direction, to another predetermined location. Hence, the present invention, utilizes the lenticular lens layer to distinguish between a right view image and a left view image, as is described herein below.

Each of the display units 108R and 108L includes a plurality of display units also known as pixels. Display unit 108L includes pixels 142A, 142B, 142C, 142D and 142E. Display unit 108R includes pixels 144A, 144B, 144C, 144D and 144E. Using these pixels each of the display units 108R and 108L produces an image, according to data provided from the processor 106. The two images, each viewed by a different eye of the user, produce a sensation of a three dimensional image.

Light rays 124A, and 126A represent a right-side image of the three-dimensional object 150. Light rays 120A, and 122A represent a left side image of the three-dimensional object 150. The optical assembly 152 redirects light rays 120A, 122A, 124A and 126A so as to focus them on a plain which is determined by the light sensor array 102, as light rays 120B, 122B, 124B and 126B, respectively. Hence, light rays 122B and 126B represent a focused right side view of the three-dimensional object 150, and light rays 120B and 124B represent a focused left side view of the three-dimensional object 150.

The lenticular lens layer 104 directs the focused right side view light rays 122B and 126B to light sensors 110 and 118, respectively, as respective light rays 122C and 126C. In addition, the lenticular lens layer 104 directs the focused left side view light rays 120B and 124B to light sensors 111 and 119, respectively. In general, light sensors 111, 113, 115, 117 and 119 detect light rays which relate to a left side view image of object 150, and light sensors 110, 112, 114, 116, and 118, detect light rays which relate to a right side view image of object 150.

Hence, light sensors 110, 112, 114, 116 and 118 detect the right side image of object 150, while light sensors 111, 113, 115, 117 and 119 detect the left side image of object 150. The light sensor array 102 provides data relating to the detected light intensity at each of the light sensors to the processor 106.

The processor 106 processes this data, produces a right side image from the data relating to the right side view and a left

side image from the data relating to the left side view, and provides the respective image to the respective display unit **108R** and **108L**. In the present example, the processor **106** utilizes the data received from sensors **110**, **112**, **114**, **116** and **118** to determine the data provided to pixels **144A**, **144B**, **144C**, **144D** and **144E**, respectively. Similarly, the processor **106** utilizes the data received from sensors **111**, **113**, **115**, **117** and **119** to determine the data which is to be provided to pixels **142A**, **142B**, **142C**, **142D** and **142E**, respectively.

According to the present invention, the right side image and the left side image are detected at the same time and hence, can also be displayed at the same time. According to another aspect of the present invention, each of the light sensors **110**, **111**, **112**, **113**, **114**, **115**, **116**, **117**, **118**, and **119**, includes a plurality of color sensing elements, which together cover a predetermined spectrum, as will be described in detail herein below.

Reference is now made to FIG. 2, which is a schematic illustration of a stereoscopic vision apparatus, generally referenced **200**, constructed and operative in accordance with another preferred embodiment of the present invention. Apparatus **200** includes a sensor assembly **202**, an interface **210**, a processor **208**, a movement detector **230**, a light source **206**, a memory unit **204**, a stereoscopic video generator **212** and a stereoscopic display **214**. The sensor assembly **202** is connected to the interface **210** by a flexible cord **218**. The interface **210** is connected to processor **208**, memory unit **204**, and to light source **206**. The processor **208** is further connected to the memory unit **204**, movement detector **230** and to the stereoscopic video generator **212**. The stereoscopic video generator **212** is further connected to the stereoscopic display **214**. Movement detector **230** detects the movement of sensor assembly **202** relative to an object. For this purpose, movement detector **230** is attached to sensor assembly **202**. In the case of a rigid endoscope, the movement detector **230** can be attached to any part of the endoscope rod (not shown), since the movement of the endoscope head can be determined according to the movement of any point of the endoscope rod. The operation of system **200**, according to data received from movement detector **230**, is described herein below.

The sensor assembly **202** includes a focusing element, which in the present example is a lens **226**, a lenticular lens layer **222**, a light sensor array **220**, an interface **228** and a light projecting means **224**. The lenticular lens layer **222** is attached to the light sensor array **220**. According to the invention, the light sensor array **220** can be any type of sensing array, such as a CCD detector, a CMOS detector, and the like. The light sensor array **220** is connected to the interface **228**, which can also act as a supporting base.

The stereoscopic display **214** includes two display units, a left display unit **216L** (for placing in front of the left eye of the user) and a right display unit **216R** (for placing in front of the right eye of the user). Hence, the stereoscopic display **214** is capable of displaying stereoscopic images continuously. Such a stereoscopic display unit is for example the ProView 50 ST head-mounted display, manufactured and sold by Kaiser Electro-Optics Inc., a US registered company, located in Carlsbad, Calif. Another example for a stereoscopic display unit is the virtual retinal display (VRD) unit, which is provided by MICROVISION Inc., a US registered company, located in Seattle, Wash. It is noted that any method, which is known in the art for displaying stereoscopic, and for that matter three-dimensional images, is applicable for the present invention.

The image received from a three-dimensional object is received at the sensor assembly **202**, focused by lens **226**, optically processed by the lenticular lens layer **222** and finally

detected by the light sensor array **220**. The lenticular lens layer **222** directs light coming from one predetermined direction to predetermined light sensors of the light sensor array **220**, and light coming from another predetermined direction to other predetermined light sensors of the light sensor array **220**. Accordingly, light sensor array **220** detects two images of the same object, a right side image and a left side image, each from a different direction. This aspect of the invention is described in detail hereinabove, in conjunction with FIG. 1.

An electronic representation of this information is partially processed by the interface **228** and then provided to the interface **210**, via flexible cord **218**. It is noted that flexible cord **218** includes digital communication linking means such as optic fibers or electrical wires, for transferring data received from light sensor array **220**, as well as light guiding conducting means for conducting light from light source **206** to the light projecting means **224**. According to the present invention, flexible cord **218** can be replaced with a rigid cord (not shown), if necessary.

The data received at interface **210** includes information, which relates to the two images and has to be processed so as to distinguish them from each other. As the processor **208** processes the information, it uses the memory unit **204** as temporarily storage.

After processing the information, the processor **208** produces two matrices each being a reconstructed representation relating to one of the originally detected images. The processor provides these matrixes to the stereoscopic video generator **212**, which in turn produces two respective video signals, one for the left view image and another for the right view image.

The stereoscopic video generator **212** provides the video signals to the stereoscopic display **214**, which in turn produces two images, one using right display unit **216R** and another using left display unit **216L**.

It is noted that the general size of the sensor assembly **202** is dictated by the size of the sensor array and can be in the order of a few millimeters or a few centimeters. This depends on the size of each of the sensors in the array and the total number of sensors (i.e. the required optical resolution).

According to one aspect of the invention, each of the sensors in light sensor array **220**, is a full range sensor, which yields data relating to a gray scale stereoscopic image. According to another aspect of the invention, each of the sensors in the light sensor array, can be adapted so as to provide full color detection capabilities.

Reference is now made to FIG. 3A, which is a schematic illustration of a super-pixel, generally referenced **300**, constructed and operative in accordance with a further preferred embodiment of the present invention. Super-pixel **300** includes a left section of sensors which includes three sensors **302**, **304** and **306**, and a right section of sensors which also includes three sensors **308**, **310** and **312**. Sensors **302** and **310** detect generally red colored light, sensors **304** and **312** detect generally green colored light and sensors **306** and **308** detect generally blue colored light. Hence, each of the sections includes a complete set of sensors for detecting light in the entire visible spectrum.

Reference is further made to FIG. 3B, which is a schematic illustration of the super-pixel **300** of FIG. 3A and a lenticular element, generally referenced **318**, constructed and operative in accordance with another preferred embodiment of the present invention. The lenticular element **318** is located on top of super-pixel **300**, where its right side covers the right section of the super-pixel **300**, and its left side covers the left section of the super-pixel **300**. Accordingly, the lenticular element **318** directs light, which arrives from the right (right

view image), to the left section of the super-pixel **300**, where it is detected in full spectrum by sensors **302**, **304** and **306**.

The data provided by these sensors can later be utilized to reconstruct an image in full color. Similarly, the lenticular element **318** directs light, which arrives from the left (left view image), to the right section of the super-pixel **300**, where it is detected in full spectrum by sensors **308**, **310** and **312**.

Reference is now made to FIG. 3C, which is a schematic illustration of a sensor array, generally referenced **330**, and a lenticular lens layer, generally referenced **332**, constructed and operative in accordance with a further preferred embodiment of the present invention. Sensor array **330** is; a matrix of MxN super-pixels, which are generally referenced **340**. For example, the upper left super-pixel is denoted $340_{(1,1)}$, the last super-pixel in the same column is denoted $340_{(1,N)}$ and the lower-right pixel is denoted $340_{(M,N)}$. A lenticular lens layer **332** of which three lenticular elements are shown (referenced **334**), is placed over the sensor array **330**.

Lenticular element $334_{(1)}$ covers the first column of super-pixels **340** from super-pixel $340_{(1,1)}$ to super-pixel $340_{(1,N)}$. Lenticular element $334_{(2)}$ covers the second column of super-pixels **340** from super-pixel $340_{(2,1)}$ to super-pixel $340_{(2,N)}$. Lenticular element $334_{(3)}$ covers the third column of super-pixels **340** from super-pixel $340_{(3,1)}$ to super-pixel $340_{(3,N)}$. Accordingly, each of the lenticular elements of the lenticular lens layer covers an entire column of super-pixels.

It is noted that a super-pixel according to the present invention can include sensors in any set of colors such as red-green-blue (RGB), cyan-yellow-magenta-green (CYMG), infrared, ultra-violet, and the like, in any arrangement or scheme such as columns, diagonals, and the like. It is noted that such a set of colors can be achieved either by using specific color sensitive detectors or by using color filters over the wide spectrum detectors.

Reference is further made to FIG. 4, which is a schematic illustration of a super-pixel, generally referenced **350**, constructed and operative in accordance with another preferred embodiment of the present invention. Super-pixel **350** includes a left section of sensors which includes four sensors **352**, **354**, **356** and **358** and a right section of sensors which also includes four sensors **360**, **362**, **364** and **366**. Sensors **352** and **366** detect generally cyan colored light, sensors **354** and **360** detect generally yellow colored light, sensors **356** and **362** detect generally magenta colored light and sensors **358** and **364** detect generally green colored light. Hence, each of the sections includes a complete set of sensors for detecting light in the entire visible spectrum.

Reference is further made to FIGS. 5A, 5B and 5C. FIG. 5A is a schematic illustration of a super-pixel, generally referenced **370**, constructed and operative in accordance with a further preferred embodiment of the present invention. FIG. 5B is a schematic illustration of super-pixel **370** combined with a single lenticular element, generally referenced **384**, constructed and operative in accordance with another preferred embodiment of the present invention. FIG. 5C is a schematic illustration of super-pixel **370** combined with three lenticular elements, generally referenced **386**, constructed and operative in accordance with a further preferred embodiment of the present invention.

The color arrangement which is provided for super-pixel **370** is typical for vertical light detection arrays, where each column of sensors is coated with light filtering layer of a different color. As can be seen in FIG. 5A, super-pixel **370** includes a plurality of light sensors **372**, **374**, **376**, **378**, **380** and **382**. Light sensors **372** and **378** are blue color range

sensors. Light sensors **374** and **380** are green color range sensors. Light sensors **376** and **382** are red color range sensors.

Reference is now made to FIG. 6, which is a schematic illustration of a sensor, generally referenced **390**, and a lenticular lens layer, generally referenced **392**, constructed and operative in accordance with another preferred embodiment of the present invention. Sensor **390** is logically divided into a plurality of super-pixels, generally referenced $394_{(x,y)}$. For example, the upper-left super-pixel is referenced $394_{(1,1)}$ and the lower-right side super-pixel is referenced $394_{(M,N)}$.

As can be seen from FIG. 6, the color arrangement of sensor **390** is diagonal. Hence, each super pixel has a different color arrangement, and generally speaking, there are several types of super-pixels, such as red-blue (super pixel $394_{(M-2,N)}$), green-red (super pixel $394_{(M-1,N)}$) and blue-green (super pixel $394_{(M,N)}$).

Reference is now made to FIG. 7A, which is a schematic illustration of a method for operating apparatus **200**, operative in accordance with a further preferred embodiment of the present invention. In step **400**, the apparatus **200** splits light which arrives from different directions, utilizing the lenticular lens **222**. Each of the lenticular elements produces two light sectors, one sector which includes light rays arriving from the left side, and another sector which includes light rays arriving from the right side.

In step **402**, the apparatus detects each light sector separately, using a plurality of light detectors, each detecting a portion of its respective sector. With reference to FIG. 3B, sensors **302**, **304** and **306** detect light which arrives from the lenticular element **318**, at the left side sector and sensors **308**, **310** and **312** detect light which arrives from the lenticular element **318**, at the right side sector. Each of the sensors detects light at a sub-sector.

In step **404**, the apparatus **200** determines the light characteristics as detected by each of the light sensors, at each of the sub-sectors. In step **408**, the apparatus **200** utilizes the data, which was accumulated from selected sub-sectors to determine and produce an image representing a view from one side. In step **406**, the apparatus **200** utilizes the data, which was accumulated from other selected sub-sectors to determine and produce an image representing a view from another side. In step **410**, the apparatus **200** displays both images using a continuous stereoscopic display device.

According to a further aspect of the invention, information from selected pixels can be used to enhance information for other pixels. For example, color information of pixels, which are associated with a first color, is used for extrapolating that color at the location of another pixel, associated with a second color.

Reference is further made to FIGS. 7B and 7C. FIG. 7B is an illustration in detail of step **406** of FIG. 7A. FIG. 7C is a schematic illustration of a sensor array, generally referenced **450**, and a lenticular lens layer, generally referenced **452**, constructed and operative in accordance with another preferred embodiment of the present invention. Sensor array **450** includes a plurality of pixel sensors, referenced **454**, each associated with a selected color. For example, pixel sensors $R_{(1,1)}$, $R_{(2,2)}$, $R_{(3,3)}$, $R_{(4,4)}$, $R_{(1,4)}$ and $R_{(4,1)}$ are associated with the red color. Pixel sensors $G_{(2,1)}$, $G_{(3,2)}$, $G_{(4,3)}$, $G_{(1,3)}$ and $G_{(2,4)}$ are associated with the green color. Pixel sensors $B_{(1,2)}$, $B_{(2,3)}$, $B_{(3,4)}$, $B_{(3,1)}$ and $B_{(4,2)}$ are associated the blue color.

In step **420**, the system, according to the invention, selects a pixel sensor, associated with a first color. With reference to FIG. 7C, the selected pixel sensor according to the present example is pixel sensor $R_{(3,3)}$.

In step 422, the system determines pixels, associated with a second color, in the vicinity of the selected pixel. It is noted that these pixels can also be restricted to ones, which relate to the same image side of the selected pixel. With reference to FIG. 7C, the second color is green and the green pixel sensors, in the vicinity of pixel sensor $R_{(3,3)}$, respective of the same image side are pixel sensors $G_{(5,1)}$, $G_{(3,2)}$, $G_{(3,5)}$, $G_{(5,4)}$, and $G_{(1,3)}$.

In step 424, the system calculates an approximation of the level of the green color at the location of the selected pixel $R_{(3,3)}$. It is noted that the calculation can include a plurality of approximation procedures, such as calculating the weighted average level, depending on the location of pixel sensors $G_{(5,1)}$, $G_{(3,2)}$, $G_{(3,5)}$, $G_{(5,4)}$, and $G_{(1,3)}$, with respect to the location of the selected pixel sensor $R_{(3,3)}$. Similarly, blue color level at the location of the selected pixel sensor $R_{(3,3)}$, can be calculated using the information received from pixel sensors $B_{(1,2)}$, $B_{(1,5)}$, $B_{(3,1)}$, $B_{(3,4)}$ and $B_{(5,3)}$. Hence the present invention provides a method for enhancing picture resolution by means of color information interpolation, using image processing.

It is noted that none of the lenticular elements is necessarily round shaped, but can be formed according to other optical structures which are based on various prism designs, and the like, which provide the directing of beams of light coming from different directions to different directions.

Reference is now made to FIG. 8, which is a schematic illustration of a stereoscopic vision apparatus, generally referenced 500, constructed and operative in accordance with a further preferred embodiment of the present invention. Apparatus 500 includes a sensor assembly 502, a frame grabber 510, a processor 508, a light source 506, a memory unit 504, a stereoscopic video generator 512 and a stereoscopic display 514. The sensor assembly 502 is connected to the frame grabber 510 by a flexible cord 518. The frame grabber 510, the processor 508, the memory unit 504 and the stereoscopic video generator 512 are all interconnected via a common bus.

The sensor assembly 502 is generally similar to the sensor assembly 202, as described herein above in conjunction with FIG. 2. The sensor assembly 502 includes a lens 526, a lenticular lens layer 522, a light sensor array 520, an analog to digital converter (AND) 528 and a light projecting means 524. The lenticular lens layer 522 is attached to the light sensor array 520. Light sensor array 520 is connected to the A/D 528, which could also act as a supporting base. The light projecting means 524 is connected to light source 506, which provides light thereto.

The stereoscopic display 514 includes two display units, a left display unit 516L (for placing in front of the left eye of the user), and a right display unit 516R (for placing in front of the right eye of the user). Hence, the stereoscopic display 514 is capable of displaying stereoscopic images continuously. A/D converter 528 converts analog information received from light sensor array 522 into digital format and provides the digital information to frame grabber 510.

The digital information is received by the frame grabber 510 and hence made available to the processor 508 via the bus. As the processor 508 processes the information, it uses the memory unit 504 as temporary storage. After processing the information, the processor 508 produces two matrices each being a reconstructed representation relating to one of the originally detected images. The processor 508 provides these matrices to the stereoscopic video generator 512, which in turn produces two respective video signals, one for the left view image and another for the right view image. The stereoscopic video generator 512 provides the video signals to the

stereoscopic display 514, which in turn produces two images, one using right display unit 516R and another using left display unit 516L.

Reference is now made to FIGS. 9A, 9B and 9C. FIG. 9A is a view in perspective of a super-pixel, generally referenced 550, and a lenticular element, generally referenced 552, constructed and operative in accordance with another preferred embodiment of the present invention. FIG. 9B is a view from the bottom of the lenticular element 552 and the super-pixel 550 of FIG. 9A. FIG. 9C is a view from the side of the lenticular element 552 and the super-pixel 550 of FIG. 9A.

The super-pixel 550 includes four sensor sections, 554, 556, 558 and 560, arranged in a rectangular formation. The lenticular element 552 is shaped like a dome and is basically divided into four sections, each facing a different one of the sensor sections 554, 556, 558 and 560.

The super-pixel 550 and the lenticular element 552 form together, an optical detection unit, which is capable of detecting and distinguishing light which arrives from four different directions. The lenticular element 552 directs a portion of the upper-left side view of the detected object to sensor section 554 and directs a portion of the lower-left side view of the detected object to sensor section 556. In addition, the lenticular element 552 directs a portion of the upper-right side view of the detected object to sensor section 560 and a portion of the lower-right side view of the detected object to sensor section 558.

It is noted that according to a further aspect of the invention, the four-direction arrangement, which is described in FIGS. 9A, 9B and 9C can be used to logically rotate the image which is provided to the user, without physically rotating the device itself. At first, sensor sections 560 and 558 are used to form the right-side image and sensor sections 554 and 556 are used to form the left-side image. A rotation at an angle of 90° clockwise, is provided by assigning sensor sections 554 and 560, to form the right side image, and assigning sensor sections 556 and 558, to form the left-side image. It is further noted that a rotation in any desired angle can also be performed by means of a linear or other combination of sensor sections, when reconstructing the final images.

Reference is now made to FIG. 10, which is a view in perspective of a section of light sensors, generally referenced 570, and a lenticular element, generally referenced 572, constructed and operative in accordance with a further preferred embodiment of the present invention. Lenticular element 572 is extended to cover the entire area of the section of pixels, so as to enhance light transmission thereto.

Reference is now made to FIG. 11, which is a view in perspective of a sensor array, generally referenced 580, and a lenticular lens layer, generally referenced 582, constructed and operative in accordance with another preferred embodiment of the present invention. The lenticular lens layer 582 includes a plurality of four direction lenticular elements such as described in FIGS. 9A and 10. The sensor array 580 is logically divided into a plurality of sensor sections, generally referenced $584_{(x,y)}$. For example, the upper left sensor section is referenced $584_{(1,1)}$ and the lower-right sensor section is referenced $584_{(M,N)}$. Each of the sensor sections is located beneath a lenticular element and detects light directed thereby.

Reference is now made to FIGS. 12A and 12B. FIG. 12A is a schematic illustration of a detection apparatus, generally referenced 600, constructed and operative in accordance with a further preferred embodiment of the present invention. FIG. 12B is another schematic illustration of detection apparatus 600, of FIG. 12A.

Detection apparatus **600** includes an optical assembly **602**, a lenticular lens layer **604** and an array of sensors **608**. The detection apparatus **600** detects images of an object **610**, which includes a plurality of object sections **610A**, **610B**, **610C** and **610D**.

Sensor array **608** includes a plurality of super-pixels **608A**, **608B**, **608C** and **608D**. Each of these super-pixels is divided into a left-side section and a right-side section. For example, super-pixel **608A** includes a left-side section, designated **608A_L** and a right-side section, designated **608A_R**.

The optical assembly **602** is divided into two optical sections **602_L** and **602_R**, each directed at transferring an image, which represents a different side view. Optical section **602_R** transfers an image, which is a view from the right side of object **610**. Optical section **602_L** transfers an image, which is a view from the left side of object **610**.

A plurality of light rays **612**, **614**, **616** and **618** are directed from all sections of the object **610** to the left side of optical assembly **602** (i.e., optical section **602_L**), and are directed to the lenticular lens layer **604**. Here, these rays are further directed to the left-side view associated sensor sections, which are sensor sections **608_L** (i.e., sensor sections **608A_L**, **608B_L**, **608C_L** and **608D_L**).

With reference to FIG. 12B, a plurality of light rays **622**, **624**, **626** and **628** are directed from all sections of the object **610** to the right side of optical assembly **602** (i.e., optical section **602_R**), and are directed to the lenticular lens layer **604**. Here, these rays are further directed to the right-side view associated sensor sections, which are sensor sections **608A_R**, **608B_R**, **608C_R** and **608D_R**.

Reference is now made to FIG. 13, which is a schematic illustration of a detection apparatus, generally referenced **630**, constructed and operative in accordance with another preferred embodiment of the present invention. Detection apparatus **630** includes an optical assembly, which is divided into four sections **632**, **634**, **636** and **638**, a lenticular lens layer **642** and an array of sensors **640**. The detection apparatus **630** detects images of an object **648**, which includes a plurality of object sections **648A**, **648B**, **648C**, **648D**, **648E** and **648F**. Light rays, which arrive from object **648** to any of the optical sections, are directed to a lenticular element of the lenticular lens layer **642**, according to their origin.

In the present example, all of the light rays **646A**, **646B**, **646C** and **646D** arrive from object element **648A**. Each of these rays is received at a different optical section. Ray **646A** is received and directed by optical section **636**, ray **646B** is received and directed by optical section **638**, ray **646C** is received and directed by optical section **634** and ray **646D** is received and directed by optical section **632**. Each of the optical sections directs its respective ray to a specific lenticular element **642_(1,1)**, at the right side of the lenticular lens layer **642**. The location of lenticular element **642_(1,1)** is respective of the location of the object element **648A**. The lenticular element **642_(1,1)** directs each of the rays to predetermined light sensors within its respective super-pixel **640_(1,1)**.

In accordance with a further aspect of the present invention, there is provided a reduced size color stereovision detection system, which uses time-multiplexed colored light projections, and respective time-multiplexed frame grabbing.

Reference is now made to FIGS. 14A and 14B. FIG. 14A is a partially schematic, partially perspective illustration of a combined illumination and detection device, generally referenced **650**, constructed and operative in accordance with a further preferred embodiment of the present invention. FIG. 14B is a partially schematic, partially perspective illustration of the combined illumination and detection device **650** of FIG. 14A, a controller, generally designated **662**, and output

frames, constructed and operative in accordance with another preferred embodiment of the present invention.

Device **650** includes a lenticular lens layer **652**, a full spectrum sensor array **654**, an optical assembly **660** and an illuminating unit **656**, surrounding the optical assembly **660**. Illuminating unit **656** includes a plurality of illuminating elements, generally referenced **658**, each being of a specific predetermined color. Illuminating elements **658_{RED}** produce generally red light, illuminating elements **658_{GREEN}** produce generally green light and illuminating elements **658_{BLUE}** produce generally blue light. It is noted that each of the illuminating elements can be of a specific color (i.e., a specific wavelength), a range of colors (i.e., a range of wavelengths) or alternating colors, for example, a multi-color light emitting diode (LED).

Each group of illuminating elements, which are of the same color, is activated at a different point in time. For example, illuminating elements **658_{RED}** are activated and shut down first, illuminating elements **658_{GREEN}** are activated and shut down second and illuminating elements **658_{BLUE}** are activated and shut down last. Then the illuminating sequence is repeated.

With reference to FIG. 14B, the controller **662** is connected to the sensor array **654** and to the illuminating unit **656**. The sensor array **654** includes full spectrum sensors, which are capable of detecting red, green and blue light, but cannot indicate the wavelength of the detected light. The controller **662** associates the images, which are detected at any particular moment, using the sensor array **654**, with the color of the illuminating elements, which were active at that particular moment.

Hence, the first detected frame **664** in an illumination sequence is considered red, since the illuminating elements which were active at that time, were illuminating elements **658_{RED}**. Similarly, the second detected frame **666** in an illumination sequence is considered green, since the illuminating elements, which were active at that time, were illuminating elements **658_{GREEN}**. Finally, the last detected frame **668** in an illumination sequence is considered blue, since the illuminating elements, which were active at that time, were illuminating elements **658_{BLUE}**. It is noted that any other combination of colors is applicable for this and any other aspect of the present invention, such as CYMG, and the like.

Reference is now made to FIG. 15, which is an illustration in perspective of a color illumination unit, generally referenced **670**, constructed and operative in accordance with a further preferred embodiment of the present invention. Unit **670** includes a light-guiding element **671**, which is generally shaped as an open-cut hollow cone, having a narrow section **674** and a wide section **672**. A detection head according to the invention, such as described in FIG. 2 (referenced **202**), can be placed within the hollow space of the light-guiding element **671**. A multi-color light source **680** can be connected to the narrow section **674**. Light, such as light ray **678**, which is emitted from the light source **680**, is directed via the light guiding element **671**, and is projected through the wide section **672**.

According to a further aspect of the invention, a remote multi-color light source **682** can be connected to the narrow section **674** via additional light guiding members such as optic-fibers **684**. Light, such as light ray **676**, which is emitted from the light source **682**, is directed via the light guiding members **684** to the narrow section **674**. The light-guiding element **671** guides light ray **676**, and projects it through the wide section **672**. This arrangement is useful when using an external light source, which is to be placed outside the inspected area (for example, outside the body of the patient).

According to a further aspect of the invention, a full spectrum illumination unit, which produces white light, is combined with a device such as sensor assembly **202** (FIG. 2).

Reference is now made to FIG. 16, which is a view in perspective of a sensor array, generally referenced **700**, and a partial lenticular lens layer, generally referenced **702**, constructed and operative in accordance with another preferred embodiment of the present invention. The partial Lenticular lens layer **700** includes a plurality of four direction lenticular elements **702** such as described in FIGS. 9A and 10. The sensor array **700** is logically divided into a plurality of sensor sections, generally referenced $704_{(x,y)}$. For example, the upper left sensor section is referenced $704_{(1,1)}$ and the lower-right sensor section is referenced $704_{(M,N)}$. Some of the sensor sections, in the perimeter, are located beneath lenticular elements and others, such as the sensor sections in the center rectangle, which is defined by sensor sections $704_{(4,3)}$ - $704_{(7,6)}$ are not. Accordingly, the sensors which are located at the center rectangle can not be used to provide multi-direction (stereoscopic or quadrosopic) information. Instead, these sensors provide enhanced resolution monoscopic information.

Reference is now made to FIG. 17, which is a view in perspective of a sensor array, generally referenced **720**, and a partial lenticular lens layer, generally referenced **722**, constructed and operative in accordance with a further preferred embodiment of the present invention. The partial lenticular lens layer **720** includes a plurality of four direction lenticular elements such as described in FIGS. 9A and 10. The sensor array **720** is logically divided into a plurality of sensor sections, generally referenced $724_{(x,y)}$. For example, the upper left sensor section is referenced $724_{(1,1)}$ and the lower-right sensor section is referenced $724_{(M,N)}$. Here, some of the sensor sections, in the center, (such as sensor section $724_{(4,2)}$) are located beneath lenticular elements and others, such as the sensor sections in the perimeter (such as sensor section $724_{(1,2)}$) are not. Accordingly, the sensors which are located at the center provide multi-direction (stereoscopic or quadrosopic) information and the ones in the perimeter provide enhanced resolution monoscopic information.

In accordance with a further aspect of the present invention there is provided a partial lenticular lens layer, which includes spaced apart lenticular elements. Reference is now made to FIG. 18, which is a schematic illustration of a sensor array, generally referenced **740**, and a partial lenticular lens layer, generally referenced **742**, constructed and operative in accordance with another preferred embodiment of the present invention.

The partial lenticular lens layer **742** includes a plurality of lenticular elements designated $744_{(1)}$, $744_{(2)}$ and $744_{(3)}$. Lenticular element $744_{(1)}$ is located over the first two left columns of color sensors, generally referenced $746_{(1)}$, of sensor array **740**. Hence, the information received from these first two left columns of color sensors of sensor array **740** contains stereoscopic information. The third and fourth columns of color sensors, generally designated $746_{(2)}$, of sensor array **740** do not have a lenticular element located thereon, and hence, cannot be used to provide stereoscopic information.

Similarly, lenticular elements $744_{(2)}$ and $744_{(3)}$ are located over color sensor column pairs, $746_{(3)}$ and $746_{(5)}$, respectively, while color sensor column pairs, $746_{(4)}$ and $746_{(6)}$ are not covered with lenticular elements.

Reference is now made to FIG. 19, which is a schematic illustration of a sensor array, generally referenced **760**, and a partial lenticular lens layer, generally referenced **762**, constructed and operative in accordance with another preferred embodiment of the present invention. Lenticular lens layer

762 includes a plurality of lenticular elements, referenced $764_{(1)}$, $764_{(2)}$, $764_{(3)}$ and $764_{(4)}$, being of different sizes and located at random locations over the sensor array **760**. It is noted that any structure of partial lenticular lens layer is applicable for the invention, whereas the associated image processing application has to be configured according to the coverage of that specific lenticular lens layer, and to address covered sensors and uncovered sensors appropriately.

In accordance with a further aspect of the present invention, there is provided a system, which produces a color stereoscopic image. The structure of the stereoscopic device defines at least two viewing angles, through which the detector can detect an image of an object. According to one aspect of the invention, the stereoscopic device includes an aperture for each viewing angle. Each of the apertures can be opened or shut. The stereoscopic device captures a stereoscopic image, by alternately detecting an image of an object, from each of the viewing angles, (e.g., by opening a different aperture at a time and shutting the rest) through a plurality of apertures, (at least two), each time from a different aperture. The final stereoscopic image can be reconstructed from the images captured with respect to the different viewing angles.

The detection of stereoscopic color image is provided by illuminating the object with a sequence of light beams, each at a different wavelength, and detecting a separate image for each wavelength and aperture combination.

Reference is now made to FIGS. 20A and 20B. FIG. 20A is a schematic illustration of a system, generally referenced **800**, for producing a color stereoscopic image, in a right side detection mode, constructed and operative in accordance with a further preferred embodiment of the invention. FIG. 20B is an illustration of the system of FIG. 20A, in a left-side detection mode.

System **800** includes a multiple aperture **804**, a controller **834**, an image detector **812**, a storage unit **836**, an image processor **838**, a movement detector **814** and an illumination unit **830**. The controller **834** is connected to the multiple aperture **804**, the image detector **812**, the storage unit **836**, movement detector **814** and to the illumination unit **830**. The storage unit **836** is further connected to the image processor **838**. The multiple aperture **804** includes a plurality of apertures, generally referenced $802_{,}$, where each aperture can be activated to be open or closed. It is noted that when an aperture is open it is at least transparent to a predetermined degree to light, and when an aperture is closed, it substantially prevents the travel of light there through. Any type of controllable light valve can be used to construct each of the apertures. Movement detector **814** detects the movement of image detector **812**. The detected movement can be a linear displacement, an angular displacement, and the derivatives thereof such as velocity, acceleration, and the like. The operation of system **800**, according to data received from movement detector **814**, is described herein below in connection with FIGS. 25A, 25B, 25C, 26A, 26B and 26C.

Light valve elements are components, which have an ability to influence light in at least one way. Some of these ways are, for example: scattering, converging, diverging, absorbing, imposing a polarization pattern, influencing a polarization pattern which, for example, may be by rotation of a polarization plane. Other ways to influence light can be by influencing wave length, diverting the direction of a beam, for example by using digital micro-mirror display (also known as DMD) or by using field effect, influencing phase, interference techniques, which either block or transfer a portion of a beam of light, and the like. Activation of light valve elements, which are utilized by the present invention, can be performed either electrically, magnetically or optically. Commonly used light

valve elements are liquid crystal based elements, which either rotate or create and enforce a predetermined polarization axis.

In the present example, multiple aperture **804** includes two apertures **802_R** and **802_L**. The controller **834** further activates the multiple aperture **804**, so as to alternately open apertures **802_R** and **802_L**. In FIG. 20A, aperture **802_R** is open while aperture **802_L** is closed and in FIG. 20B, aperture **802_R** is closed while aperture **802_L** is open.

Light rays, which reflect from various sections of the object **810**, pass through the currently open aperture (**802_R** in FIG. 20A and **802_L** in FIG. 20B). Thereby, light rays **822** and **824** arrive from section **810A** of object **810**, pass through aperture **802_R**, and are detected by detection element **808A**, while light rays **826** and **828** arrive from section **810D**, pass through aperture **802_R** and are detected by detection element **808D**. Hence, when aperture **802_R** is open, the system **800** provides a right side view of the object **810**.

With reference to FIG. 20B, when aperture **802_L** is open, light rays **827** and **825** arrive from section **810A**, pass through aperture **802_L**, and are detected by detection element **808A**, while light rays **821** and **823** arrive from section **810D**, pass through aperture **802_L**, and are detected by detection element **808D**. Thereby, the system **800** provides a left side view of the object **810**.

The illumination unit **830** is a multi-color illumination unit, which can produce light at a plurality of wavelengths. The controller **834** provides a sequence of illumination commands to the illumination unit **830**, so as to produce a beam at a different predetermined wavelength, at each given moment. In the present example, the illumination unit is a red-green-blue (RGB) unit, which can produce a red light beam, a green light beam and a blue light beam. It is noted that illumination unit **830** can be replaced with any other multi-color illumination unit, which can produce either visible light, non-visible light or both, at any desired wavelength combination (CYMG and the like).

Furthermore, illumination unit **830** can be a passive unit, where it receives external commands to move from one wavelength to another, or it can be an active unit, which changes wavelength independently and provides an indication of the currently active wavelength to an external controller. Illumination unit **830** of the present example is a passive unit, which enhances the versatility of the system **800**, by providing any wavelength sequence on demand.

The image detector **812** includes a plurality of detection elements **808A**, **808B**, **808C** and **808D**. In accordance with one aspect of the invention, image detector **812** is a full range color detector, where each of the detection elements is operative to detect light in a plurality of wavelengths. In accordance with another aspect of the invention, the image detector **812** is a color segmented detector, where the detection elements are divided into groups, each operative to detect light in a different range of wavelengths. One conventional type of such detectors includes a full range detection array, which is covered by a color filter layer, where each detection element is covered by a different color filter. Accordingly, some of the detection elements are covered with red filters, others are covered with green filters and the rest are covered with blue filters.

The present invention enhances the color resolution of systems, using such color detectors. It will be appreciated by those skilled in the art that a color segment detector of poor quality may exhibit a wavelength (color) overlap between the different detection elements. For example, when the filters are of poor quality, their filtering functions tend to overlap such that the red filter also passes a small amount of either green or blue light. Hence, the detection element behind the red filter,

also detects that small amount of green or blue light, but provides an output measurement as a measurement of red light. Hence, the color detector produces an image, which includes incorrect measurements of red light (e.g. more than the actual red light, which arrived at the detector) as result of that overlap. Accordingly, received information of the inspected object is not valid.

In the present invention, the illumination unit **830** produces a sequence of non-overlapping illumination beams at predetermined wavelengths (i.e., red, blue and green). As explained above, the color detector detects an image, which includes incorrect measurements, as a result of the wavelength (color) filtering overlap. Since the illumination unit **830** and the image acquisition process are synchronized, the imaging system can process each of the acquired images, according to the actual light beam color, which was produced therewith. For example, the illumination unit **830** produces blue light illumination beam. At the same time the image detector **812** detects an image, which also includes actual light measurements in detection elements, which are covered with green and red filters, due to the wavelength overlap. The imaging system can discard light measurements, which are received from detection elements, covered with color filters, which are not blue (e.g., red and green).

Such sequenced color illumination of the object, provides enhanced color resolution, for color image detectors of poor quality, and obtains the valid color images of the inspected object. System **800** can further include a stereoscopic display unit (not shown), connected to controller **834** for displaying a stereoscopic image of object **810**.

Reference is further made to FIG. 21A, which is a schematic illustration of a timing sequence, in which controller **834** (FIG. 20A) synchronizes the operation of illumination unit **830**, apertures **802_L** and **802_R**, and image detector **812**. Signal **840** represents the timing sequence of the left aperture **802_L**. Signal **842** represents the timing sequence of the right aperture **802_R**. Signal **844** represents the timing sequence of the blue light beam, produced by the illumination unit **830**. Signal **846** represents the timing sequence of the green light beam, produced by the illumination unit **830**. Signal **848** represents the timing sequence of the red light beam, produced by the illumination unit **830**. Signal **841** represents the timing sequence of the image detector **812**, where each image is downloaded therefrom.

Timing sequence **841** rises every time any of the rises of sequences **844**, **846** and **848** intersect with a rise of either sequence **842** or sequence **840**. For example, rise **841_A** indicates a frame download of a blue light—right aperture combination, rise **841_B** indicates a frame download of a green light—right aperture combination, and rise **841_C** indicates a frame download of a red light—right aperture combination. Similarly, rise **841_D** indicates a frame download of a blue light—left aperture combination, rise **841_E** indicates a frame download of a green light—left aperture combination and rise **841_F** indicates a frame download of a red light—left aperture combination.

It is noted that for some light sources, the produced light beams do not cover the full range of visible light. For such light sources, the missing color components can be reconstructed (interpolated) taking into consideration the physiological assumption, that color reflection response as a function of reflected angle, does not change much with angle.

Reference is further made to FIG. 22, which is a schematic illustration of a method for operating system **800** of FIGS. 20A and 20B, operative in accordance with another preferred embodiment of the present invention. In step **870**, a sequence of illumination beams at predetermined wavelengths is pro-

duced. With reference to FIGS. 20A and 20B, controller 834 provides a sequence of illumination commands to the illumination unit 830, which in turn produces different wavelength light beams, generally referenced 832, at predetermined points in time, towards an object, generally referenced 810.

In step 872 right and left apertures are alternated. Light rays, which reflect from various sections of the object 810, pass through the currently open aperture (802_R in FIG. 20A and 802_L in FIG. 20B). With reference to FIGS. 20A and 20B, controller 834 provides a sequence of operating commands to the apertures 802_L and 802_R. In step 874, a plurality of frames, each for a selected aperture and wavelength combination is detected. Controller 834 operates the image detector 812 so as to detect a plurality of frames, each respective of a selected aperture and wavelength combination.

Light rays 822 and 824 (FIG. 20A) arrive from section 810A of object 810, pass through aperture 802_R, and are detected by detection element 808A, while light rays 826 and 828 arrive from section 810D, pass through aperture 802_R and are detected by detection element 808D. It is noted that in the present example, an imaging element (not shown) is introduced in the vicinity of multiple aperture 804. Hence, when aperture 802_R is open, the system 800 provides a right side view of the object 810.

Light rays 827 and 825 (FIG. 20B) arrive from section 810A, pass through aperture 802_L and are detected by detection element 808A, while light rays 821 and 823 arrive from section 810D, pass through aperture 802_L and are detected by detection element 808D. Hence, when aperture 802_L is open, the system 800 provides a left side view of the object 810.

With reference to FIG. 21A, rise 841_A provides a right side blue image (reference 806_B^R of FIG. 20A), rise 841_B provides a right side green image (reference 806_G^R of FIG. 20A), and rise 841_C provides a right side red image (reference 806_R^R of FIG. 20A). Similarly, rise 841_O provides a left side blue image (reference 806_B^L of FIG. 20B), rise 841_E provides a left side green image (reference 806_G^L of FIG. 20B), and rise 841_F provides a left side red image (reference 806_R^L of FIG. 20B). With reference to FIGS. 20A and 20B, image detector 812 detects the plurality of frames, and provides right and left output video for image processing.

In step 876, movement between the detector and the inspected organ, at selected frequencies is detected. This movement can be detected from movement of the endoscope, by means of a movement detector, or by analyzing the detected images, where different color images exhibit different lines, with dramatic color shade changes. This information is utilized in the following step, for spatially correlating between images of different colors.

In step 878 a stereoscopic color image from the plurality of frames, according to their aperture origin is produced. With reference to FIGS. 20A and 20B, the controller 834 stores the detected images in storage unit 836. Image processor 838 retrieves the detected images from the storage unit 836, and constructs color stereoscopic images. Hence, the present invention provides an additional way for detecting a color stereoscopic image, using a single image detector for both sides and all colors.

Reference is further made to FIG. 21B, which is a schematic illustration of another timing sequence, in which controller 834 (FIG. 20A) synchronizes the operation of illumination unit 830, apertures 802_L and 802_R, and image detector 812. Signal 840' represents the timing sequence of the left aperture 802_L. Signal 842' represents the timing sequence of the right aperture 802_R. Signal 844' represents the timing sequence of the blue light beam, produced by the illumination unit 830. Signal 846' represents the timing sequence of the

green light beam, produced by the illumination unit 830. Signal 848' represents the timing sequence of the red light beam, produced by the illumination unit 830. Signal 841' represents the timing sequence of the image detector 812, where each image is downloaded therefrom.

Timing sequence 841' rises every time any of the rises of sequences 844', 846' and 848' intersects with a rise of either sequence 842' or sequence 840'. For example, rise 841'_A indicates a frame download of a blue light—right aperture combination, rise 841'_B indicates a frame download of a blue light—left aperture combination and rise 841'_C indicates a frame download of a green light—right aperture combination. Similarly, rise 841'_D indicates a frame download of a green light—left aperture combination, rise 841'_E indicates a frame download of a red light—right aperture combination and rise 841'_F indicates a frame download of a blue light—left aperture combination.

Reference is further made to FIG. 23, which is a schematic illustration of a timing scheme, for operating system 800 of FIGS. 20A and 20B, in accordance with a further preferred embodiment of the present invention. Signal 850 represents the timing sequence of the left aperture 802_L. Signal 852 represents the timing sequence of the right aperture 802_R. Signal 854 represents the timing sequence of the blue light beam. Signal 856 represents the timing sequence of the green light beam. Signal 858 represents the timing sequence of the red light beam. Signal 851 represents the timing sequence of the image detector 812, where each image is downloaded therefrom. As can be seen in FIG. 23, the timing scheme is asymmetric, where the green light beam is activated for a time period which is twice the time period of either the red light beam or the blue light beam. Signal 851 corresponds to this arrangement and provides a green image download rise (references 851_B and 851_E), after a time period which is twice as long with comparison to red image download rises (references 851_C and 851_F) or blue image download rises (references 851_A and 851_D).

Reference is further made to FIG. 24, which is a schematic illustration of a timing scheme, for operating system 800 of FIGS. 20A and 20B, in accordance with another preferred embodiment of the present invention. Signal 860 represents the timing sequence of the left aperture 802_L. Signal 862 represents the timing sequence of the right aperture 802_R. Signal 864 represents the timing sequence of the magenta light beam. Signal 866 represents the timing sequence of the yellow light beam. Signal 868 represents the timing sequence of the cyan light beam. As can be seen in FIG. 24, the timing scheme addresses an alternate wavelength scheme and is also asymmetric.

It is noted that a mechanical multi-wavelength illumination unit such as described in the prior art, can be used for implementing the present invention. However, such a system significantly reduces the capability of the user to control illumination duration, wavelength ratio and detection timing, such as described herein above.

The disclosed technique incorporates even more advanced aspects, which provide automatic image translation correction, based on correlation between the two detected images. When the endoscope is handheld, it is subjected to the vibration of the human hand, which is in the order of 10 Hz, at an angular amplitude of 1 degree. This phenomenon causes a blur of areas, where different colors intersect, and is also known as the “between color field blur” effect. It is noted that any movement between the image detector and the inspected organ can cause this phenomenon, provided it occurs at particular frequencies, defined by the structure and the manner of operation of the system.

With reference to FIGS. 20A and 20B, since the information retrieved from image detector 812 relates to specific colors, then controller 834 can correlate between such single color images to determine the ΔX and ΔY to the subsequent color, and hence compose and produce an un-blurred color image. Due to the vibrations of the human hand, while image detector 812 is substantially stationary relative to object 810, the displayed stereoscopic image of object 810 is blurred. In order to mitigate this problem, and provide a blur-free stereoscopic image of object 810 to the viewer, movement detector 230 (FIG. 2), is incorporated with system 200, and movement detector 814 is incorporated with system 800.

Reference is now made to FIGS. 25A, 25B, 25C, 26A, 26B and 26C and again to FIG. 2. FIG. 25A is a schematic illustration of an object, generally referenced 766, and a sensor assembly generally referenced 768, when the sensor assembly is located at an initial position with respect to the object. FIG. 25B is a schematic illustration of the object and the sensor assembly of FIG. 25A, when the sensor assembly has moved to a new position. FIG. 25C is a schematic illustration of the object and the sensor assembly of FIG. 25A, when the sensor assembly has moved to another position. FIG. 26A is a schematic illustration of a detected image, generally referenced 770, as detected by sensor assembly of FIG. 25A, and a respective displayed image, generally referenced 772, in accordance with a further preferred embodiment of the present invention. FIG. 26B is a schematic illustration of a detected image, generally referenced 780, as detected by sensor assembly of FIG. 25B, and a respective displayed image, generally referenced 774. FIG. 26C is a schematic illustration of a detected image, generally referenced 782, as detected by the sensor assembly of FIG. 25C, and a respective displayed image, generally referenced 776.

The foregoing description relates to one aspect of the invention, in which an stereoscopic image of an object is captured by a sensor array through a lenticular lens layer (i.e., each captured image includes all the primary colors of the color palette, such as RGB, CYMG, and the like). It is noted that the movement is determined such that it has a constant average (e.g., vibrating about a certain point).

With reference to FIGS. 25A and 26A, the center of sensor assembly 768 is located at a point O_1 relative to object 766. Sensor assembly 768 detects detected image 770 (FIG. 26A) of object 766, where the detected image 770 is composed for example, of four hundred pixels (i.e., a 20×20 matrix). Each pixel is designated by $P_{m,n}$ where m is the row and n is the column of detected image 770. For example, pixel 778_{1,1} is located in the first row and the first column of detected image 770, pixel 778_{1,2} is located in the first row and the second column, and pixel 778_{20,20} is located in row twenty and column twenty. Processor 208 selects pixels 778_{3,3} through 778_{18,18} (i.e., a total of $16 \times 16 = 256$ pixels) to display the sub-matrix 772 on stereoscopic display 214 (FIG. 2), while the center of sensor assembly 768 is located at point O_1 .

With reference to FIGS. 25B and 26B, due to the vibrations of the human hand, the center of sensor assembly 768 has moved to a point O_2 relative to object 766. Point O_2 is located a distance ΔX_1 to the right of point O_1 and a distance ΔY_1 below point O_1 . In this case the length of ΔX_1 is equal to the horizontal width of two pixels of detected image 780, and the length ΔY_1 is equal to the vertical height of minus two pixels of detected image 780. Movement detector 230 detects the movement of sensor assembly 768 from point O_1 to point O_2 , and sends a signal respective of this movement, to processor 208.

With reference to FIG. 26B, the image of the object section that was captured by sub-matrix 772, is now captured by a

sub-matrix 774, which is shifted two pixels up and two pixels to the left. Hence, displaying sub-matrix 774, compensates for the movement of sensor assembly 768. For this purpose, processor 208 selects pixels 778_{1,1} through 778_{16,16} of detected image 780, for sub-matrix 774. Despite the movement of sensor assembly 768, the images of sub-matrices 772 and 774 are substantially of the same area, and therefore the user does not realize that sensor assembly 768 has moved from point O_1 to point O_2 .

With reference to FIGS. 25C and 26C, the center of sensor assembly 768 has moved from point O_1 to a point O_3 relative to object 766. Point O_3 is located a distance ΔX_2 to the left of point O_1 and a distance ΔY_2 above point O_1 . In this case the length of ΔX_2 is equal to the horizontal width of minus two pixels of detected image 782, and the length ΔY_2 is equal to the vertical height of one pixel of detected image 782. Movement detector 230 detects the movement of sensor assembly 768 from point O_1 to point O_3 , and sends a signal respective of this movement, to processor 208.

With reference to FIG. 26C, the image of the object section that was captured by sub-matrix 772, is now captured by a sub-matrix 776, which is shifted one pixel up and two pixels to the left. Hence, displaying sub-matrix 774, compensates for the movement of sensor assembly 768 two pixels to the left and one pixel up. For this purpose, processor 208 selects pixels 778_{5,4} through 778_{20,19} of detected image 782, for sub-matrix 776. Despite the movement of sensor assembly 768, the images of displayed images 772 and 776 are identical, and therefore the user does not realize that sensor assembly 768 has moved from point O_1 to point O_3 . Therefore, by incorporating movement detector 230 with sensor assembly 768, the viewer views a blur-free stereoscopic color image of object 766, despite the vibrations of sensor assembly 768 caused by the human hand.

It is noted that processor 208 processes the detected images 780 and 782, if the dimensions ΔX_1 , ΔX_2 , ΔY_1 and ΔY_2 are of the order of A , the amplitude of vibrations of the human hand and in the appropriate frequency. In general, processor 208 performs the compensation process, between a plurality of captured images, as long as the detected movement, is maintained about a certain average point ($X_{AVERAGE}$, $Y_{AVERAGE}$). When one of the average values $X_{AVERAGE}$ and $Y_{AVERAGE}$ changes, then processor 208 initiates a new compensation process around the updated average point, accordingly.

Reference is now made to FIGS. 25D, 25E, 25F, 27A, 27B, 27C, 27D, 27E, 27F and again to FIGS. 20A, 20B, 25A, 25B and 25C. FIG. 25D is a schematic illustration of the object and the sensor assembly of FIG. 25A, when the sensor assembly has moved to a further new position. FIG. 25E is a schematic illustration of the object and the sensor assembly of FIG. 25A, when the sensor assembly has moved to another new position. FIG. 25F is a schematic illustration of the object and the sensor assembly of FIG. 25A, when the sensor assembly has moved to a further new position. FIG. 27A is a schematic illustration of a sub-matrix, generally referenced 1064, in accordance with another preferred embodiment of the present invention, when the sensor assembly is at a location illustrated in FIG. 25A. FIG. 27B is a schematic illustration of a sub-matrix, generally referenced 1066, when the sensor assembly is at a location illustrated in FIG. 25B. FIG. 27C is a schematic illustration of a sub-matrix, generally referenced 1068, when the sensor assembly is at a location illustrated in FIG. 25C. FIG. 27D is a schematic illustration of a sub-matrix, generally referenced 1070, when the sensor assembly is at a location illustrated in FIG. 25D. FIG. 27E is a schematic illustration of a sub-matrix, generally referenced 1072, when the sensor assembly is at a location illustrated in FIG.

25E. FIG. 27F is a schematic illustration of a sub-matrix, generally referenced 1074, when the sensor assembly is at a location illustrated in FIG. 25F.

Image processor 838 (FIG. 20A), selects each of sub-matrices 1064, 1066 and 1068 from detected images 1052, 1054 and 1056, respectively, as described herein above in connection with FIGS. 26A, 26B and 26C. Analogously, image processor 838 selects each of sub-matrices 1070, 1072 and 1074 from detected images 1058, 1060 and 1062, respectively, when the center of sensor assembly 768 is directed to each of the points O_4 , O_5 , and O_6 , respectively. For example, when the center of sensor assembly 768 is directed to point O_4 , which is located to the right and above point O_1 , image processor 838 selects sub-matrix 1070 (FIG. 27D). When the center of sensor assembly 838 is directed to point O_5 directly below point O_1 , image processor 838 selects sub-matrix 1072 (FIG. 27E). When the center of sensor assembly 838 is directed to point O_6 directly above point O_1 , image processor 838 selects sub-matrix 1074 (FIG. 27F).

In the following description, object 810 (FIGS. 20A and 20B) and object 766 (FIG. 25A) are used interchangeably, although they both represent the same object. Object 810 is described in connection with multiple aperture 804 and illumination unit 830, while object 766 is described in connection with the location of sensor assembly 768 relative thereto. It is noted that during the time interval in which the opening of multiple aperture 804 switches from aperture 802_R (FIG. 20A), to aperture 802_L (FIG. 20B), sensor assembly 768 moves relative to object 766, due to the vibrations of the human hand. Thus, for example, sub-matrix 1064 (FIG. 27A) represents a right view image of object 810 corresponding to the image which image processor 838 captures, when aperture 802_R is open. On the other hand, sub-matrix 1066 (FIG. 27B) represents a left view image of object 766, when aperture 802_L is open.

Furthermore, the color of detected images 1052, 1054, 1056, 1058, 1060, and 1062 changes as described herein above for example in connection with FIG. 21B. Image processor 838 receives download image 841'_A, and selects sub-matrix 1064 (FIG. 27A), which is a right view image of object 766 (FIG. 25A) in blue, when the center of sensor assembly 768 is directed to point O_1 .

While multiple aperture 804 switches to aperture 802_L, the center of sensor assembly 768 (FIG. 25B) directs to point O_2 (FIG. 25B), and image processor 838 receives download image 841'_B. Since the center of sensor assembly 768 is directed to point O_2 (FIG. 25B), then image processor 838 selects sub-matrix 1066 (FIG. 27B) which represents a left view image of object 810 in blue. Analogously, sub-matrix 1068 (FIG. 27C) represents a green right view image of object 766 (download image 841'_C), when the center of sensor assembly 768 is directed to point O_3 (FIG. 25C). Sub-matrix 1070 (FIG. 27D) represents a green left view image of object 766 (download image 841'_D), when the center of sensor assembly 768 directs to point O_4 (FIG. 25D). Sub-matrix 1072 (FIG. 27E) represents a red right view image of object 766 (download image 841'_E), when the center of sensor assembly 768 directs to point O_5 (FIG. 25E). Sub-matrix 1074 (FIG. 27F) represents a red left view image of object 766 (download image 841'_F), when the center of sensor assembly 768 directs to point O_6 (FIG. 25F).

According to FIG. 21A, a stereoscopic display unit (not shown) displays sub-matrices 1064, 1066, 1068, 1070, 1072 and 1074 in sequence. Sub-matrices 1064, 1068 and 1072 are the right side views of substantially the same area of object 766, which together compose a right side color image of the object 766. Sub-matrices 1066, 1070 and 1074 are the left

side views of substantially the same area of object 766, which together compose a left side color image of the object 766. The stereoscopic display unit alternately displays the right view image and the left view image of substantially the same area of object 766. Thus, system 800 maintains a stable image of object 766, which does not exhibit any change in the location of object 766 as displayed on the stereoscopic display unit, despite the movement of sensor assembly 768 due to the vibrations of the human hand.

For example, image processor 838 selects sub-matrices 1064, 1068 and 1072 (FIGS. 27A, 27C and 27E, respectively), and the stereoscopic display (not shown), sequentially displays the same image in blue, green and red, respectively. Thus, the stereoscopic display presents a stable right side image of the object in full color, to the right eye. Similarly, the stereoscopic display sequentially displays sub-matrices 1066, 1070 and 1074 (FIGS. 27B, 27D and 27F, respectively), wherein the color of each sub-matrix sequentially changes from blue to green to red, respectively. In this manner, the stereoscopic display presents a stable left side image of the object in full color, to the left eye. Thus, the user views a stable full color stereoscopic image of the object, despite the movement of the endoscope due to the vibrations of the human hand.

It is noted that an RGB timing scheme can be employed. In this case, the stereoscopic display displays the sub-matrices in a sequence of right-red, left-green, right-blue, left-red, right-green and left-blue.

It is noted that the sequence of FIGS. 27A, 27B, 27C, 27D, 27E and 27F is cyclically repeated during the imaging process of the object. Other timing schemes can be employed where the download image trigger signal is used for acquiring a reading from movement detector 814, for the detected image. Examples for such timing schemes are illustrated in FIGS. 23, 24, and 21A.

It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described here in above. Rather the scope of the present invention is defined only by the claims which follow.

The invention claimed is:

1. Stereoscopic device comprising:

a sensor assembly having an optical axis, for detecting a sequence of alternating stereoscopic images of an object;

a movement detector, detecting movements of said sensor assembly perpendicular to the optical axis, relative to said object, an average of said movements being constant and defining a location of origin; and

a processing unit connected to said sensor assembly and to said movement detector,

wherein said processing unit selects corresponding portions of said alternating stereoscopic images, according to a signal received from said movement detector and compensates for detected movements, thereby producing a visually stable sequence of display images;

wherein said visually stable sequence of display images comprises a plurality of sub-matrices, each one of said sub-matrices is selected from a respective one of said stereoscopic images, each one of said sub-matrices is located at a distance equal to a respective one of said movements from said location of origin, in a direction opposite to said respective movement, relative to said location of origin, and

wherein each one of said display images has a predetermined and constant area size, the area size being smaller than that of each of said detected stereoscopic images.

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2. The stereoscopic device according to claim 1, wherein said sensor assembly comprises a lenticular lens layer and a light sensor array, wherein said lenticular lens layer is located in front of said light sensor array.

3. The stereoscopic device according to claim 2, wherein said light sensor array is a color red-green-blue (RGB) sensor array.

4. The stereoscopic device according to claim 2, wherein said light sensor array is a color cyan-yellow-magenta-green (CYMG) sensor array.

5. The stereoscopic device according to claim 1, wherein said processing unit comprises a processor connected to said movement detector and a memory unit connected to said processor.

6. The stereoscopic device according to claim 1, further comprising:

- an interface connected to said sensor assembly and to said processor;
- a light source connected to said interface;
- a stereoscopic video generator connected to said processor; and
- a stereoscopic display unit connected to said stereoscopic video generator, for producing said visually stable sequence of display images.

7. The stereoscopic device according to claim 6, wherein said light source produces light in a predetermined range of wavelengths.

8. The stereoscopic device according to claim 7, wherein said predetermined range of wavelengths is selected from the list consisting of substantially visible red color light;

- substantially visible green color light;
- substantially visible blue color light;
- substantially visible cyan color light;
- substantially visible yellow color light;
- substantially visible magenta color light;
- substantially infra-red light;
- substantially ultra-violet light; and
- visible light.

9. The stereoscopic device according to claim 6, wherein said light source produces at least two alternating beams of light, each said beams of light characterized as being in a different range of wavelengths.

10. The stereoscopic device according to claim 1, wherein said visually stable sequence of display images is stereoscopic.

11. The stereoscopic device according to claim 1, wherein said visually stable sequence of display images is partially stereoscopic.

12. The stereoscopic device according to claim 1, wherein said sensor assembly further comprises:

- at least two apertures, each said apertures including a light valve, each said light valves being operative to open at a different predetermined timing; and
 - a multi wavelength light sensor array;
- wherein said multi wavelength light sensor array detects said images, each one of said images corresponding to a predetermined combination of an open state of a selected one of said light valves and a selected one of at least two alternating beams of light.

13. The stereoscopic device according to claim 12, further comprising a controllable multi wavelength illumination unit, connected to said processing unit, said controllable multi wavelength illumination unit producing at least two alternating beams of light, each said beams of light characterized as being in a different range of wavelengths.

14. The stereoscopic device according to claim 13, wherein said controllable multi wavelength illumination unit pro-

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duces at least two alternating beams of light, each said beams of light characterized as being in a difference range of wavelengths.

15. The stereoscopic device according to claim 13, wherein each said different ranges of wavelengths associated with said multi wavelength illumination unit, is selected from the list consisting of:

- substantially visible red color light;
- substantially visible green color light;
- substantially visible blue color light;
- substantially visible cyan color light;
- substantially visible yellow color light;
- substantially visible magenta color light;
- substantially infra-red light;
- substantially ultra-violet light; and
- visible light.

16. The stereoscopic device according to claim 12, further comprising capture means, connected to said multi wavelength light sensor array, for capturing data received from said multi wavelength light sensor array.

17. The stereoscopic device according to claim 16, wherein said processing unit further comprises:

- an image processor;
- a storage unit connected to said image processor, said storage unit capturing said capturing data; and
- a controller connected to said storage unit, said movement detector, said light valves, and to said multi wavelength light sensor array, said controller timing the operation of said light valves, said multi wavelength light sensor array and said controllable multi wavelength illumination unit.

18. The stereoscopic device according to claim 17, further comprising:

- a stereoscopic video generator connected to said image processor; and
- a stereoscopic display unit connected to said stereoscopic video generator, for producing said visually stable sequence of display images.

19. The stereoscopic device according to claim 12, wherein said multi wavelength light sensor array includes at least two groups of sensors, wherein the sensors of each said group detect light in a different range of wavelengths.

20. The stereoscopic device according to claim 19, wherein each said different ranges of wavelengths associated with said sensors, is selected from the list consisting of:

- substantially visible red color light;
- substantially visible green color light;
- substantially visible blue color light;
- substantially visible cyan color light;
- substantially visible yellow color light;
- substantially visible magenta color light;
- substantially infra-red light;
- substantially ultra-violet light; and
- visible light.

21. The stereoscopic device according to claim 12, wherein said multi wavelength light sensor array includes a plurality of sensors, each of said sensors detecting light in a predetermined range of wavelengths.

22. The stereoscopic device according to claim 12, wherein said multi wavelength light sensor array is a color red-green-blue (RGB) sensor array.

23. The stereoscopic device according to claim 12, wherein said multi wavelength light sensor array is a color cyan-yellow-magenta-green (CYMG) sensor array.

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24. The stereoscopic device according to claim 12, wherein the color of each of said sub-matrices is selected from the list consisting of:

substantially visible red;
 substantially visible green;
 substantially visible blue;
 substantially visible cyan;
 substantially visible yellow; and
 substantially visible magenta.

25. The stereoscopic device according to claim 1, wherein said alternating stereoscopic images alternate between a left image and a right image.

26. Method for producing a stable sequence of stereoscopic images of an object, the method comprising the steps of:

detecting a plurality of alternating stereoscopic images, using a stereoscopic sensor assembly having an optical axis;

for each said alternating stereoscopic images, detecting movements of said stereoscopic sensor assembly perpendicular to said optical axis relative to said object, an average of said movements is constant and defining a location of origin;

for each said stereoscopic images, selecting a corresponding portion of each of corresponding ones of said stereoscopic images, according to said respective movement, said corresponding portion being a sub-matrix of a respective one of said stereoscopic images, wherein each one of said sub-matrices is located at a distance equal to a respective one of said movements from said location of origin, in a direction opposite to said respective movement, relative to said location of origin, wherein said step of selecting further comprises a sub-procedure of measuring a distance of a respective one of said movements from said location of origin, in a direction opposite to said respective movement relative to said location of origin; and

compensating for said detected movements of said stereoscopic sensor assembly, thereby producing a visually stable sequence of display images, said visually stable sequence of display images comprises a plurality of said

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sub-matrices, wherein each one of said display images has a predetermined and constant area size smaller than an area size of each of said detected stereoscopic images.

27. The method according to claim 26, further comprising a preliminary step of illuminating a detected area of said object.

28. The method according to claim 27, wherein said stereoscopic sensor assembly comprises a lenticular lens layer and a light sensor array, wherein said lenticular lens layer is located in front of said light sensor array.

29. The method according to claim 28, wherein said step of illuminating comprises a procedure of sequentially illuminating said detected area, with alternating beams of light of different ranges of wavelengths.

30. The method according to claim 28, further comprising a step of associating each one of said sub-matrices in time, with the currently illuminating ranges of wavelengths.

31. The method according to claim 27, wherein said stereoscopic sensor assembly comprises:

at least two apertures, each said apertures including a light valve, each said light valves being operative to open at a different predetermined timing; and
 a multi wavelength light sensor array,
 wherein said multi wavelength light sensor array detects said images, each one of said images corresponding to a predetermined combination of an open state of a selected one of said light valves and a selected one of at least two alternating beams of light.

32. The method according to claim 31, wherein said step of illuminating comprises a procedure of producing at least two alternating beams of light, each said beams of light characterized as being in a different range of wavelengths.

33. The method according to claim 32, further comprising a step of associating each one of said sub-matrices, at said different predetermined timing, with said different range of wavelengths.

34. The method according to claim 26, wherein said alternating stereoscopic images alternate between a left image and a right image.

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